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The Authors of Papers are alone responsible for the statements
and
the opinions expressed therein.

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The Royal Society of Western Australia (Inc.).

ANNUAL REPORT OF THE COUNCIL FOR THE YEAR ENDING 30TH JUNE, 1948.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ending 30th June, 1948.

Council.—Nine meetings of Council were held during the year. Owing to poor health, Miss Baird resigned from the Council in September, 1947 and Mr. R. D. Royce was elected to fill the vacancy.

Finance.—There is a credit balance of £301 13s. 2d. in the General Fund; the Endowment Fund amounts to £343 10s. 10d. and the Medal Fund, £12 5s. 3d. There are certain heavy commitments outstanding to Messrs, Pilpel & Co. on account of the printing of Volume XXXIII. of the Journal.

The cost of the publication of the Journal continues to rise, owing largely to increased costs of materials and labour.

Membership.—There has been a slight increase in the total membership of the Society, which now numbers two hundred and six members, made up as follows :—

Honorary Members	6
Corresponding Members	7
Life Members	2
Ordinary Members	140
Associate Members	26
Student Members	25

The names of 16 Ordinary members and one Associate member were added to the register during the year: two Associates transferred to full membership, six Ordinary members resigned and two Ordinary members have been lost to the Society through death.

Journal.—Progress has been made in bringing the publication of the Journal up to date. Volume XXXI. was published on the 9th of April, 1948 and Volume XXXII. was published last week. The printing of Volume XXXIII. is nearly completed and this volume is expected shortly.

Library.—Exchange agreements have been entered into with the University of Hawaii and the National Taiwan University, Taiwan, China.

Pre-war exhange arrangements have been resumed in a few instances and several other overseas institutions have expressed a desire to enter into exchange relations with this Society.

L. GLAUERT,
President.

S. E. TERRILL,
G. E. MARSHALL,
Joint Honorary Secretaries.

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Annual Meeting in Gledden Hall.
Presidential Address.—" Marine Biology in Western Australia," by Dr. A. G. Nicholls.

12th August, 1947—

Paper.—" An X-ray study of Western Australian Beryl," by Mr. K. Norrish.

Address.—" Atomic Power Plants," by Dr. S. E. Williams.

Election.—Mr. J. C. McMath, Mr. A. Reid, Mr. D. Burns as Ordinary Members. Mr. E. B. Brett as an Associate Member.

9th September, 1947—

Business postponed until October meeting due to the lack of a quorum.

14th October, 1947—

Address.—" Angora and other fibres," by Mr. C. B. Palmer.

Election.—Miss B. Sherzinger, Mr. V. Gardiner, Mr. R. F. Levinson, Mr. R. P. Donnelly as Ordinary Members.

11th November, 1947—

Paper.—" Observation on radio-frequency radiation from the sun," by Dr. S. E. Williams.

Election.—Mr. G. W. Rayner and Miss R. E. Stewart (transferred from Associate) as Ordinary Members.

9th December, 1947—

Address.—" Some Introduced Plants," by Mr. C. A. Gardner.

Election.—Mr. V. N. Serventy and Mr. R. A. Hobson (transferred from Associate) as Ordinary Members.

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Address.—(1) " Wool Growth," by Mr. A. Stewart.
(2) " The Salt Lake Problem in W.A.", by Mr. K. C. Tiller.

Election.—Dr. A. H. Voisey as an Ordinary Member.

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Address.—" Random observations in the Antarctic seas," by Mr. R. G. Rayner.

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(ii) " Plant Genetics," by Mr. C. B. Palmer.

Address.—" Anaemias," by Dr. E. R. Beech.

Election.—Dr. B. J. Grieve, Mr. N. M. Gray, Mr. K. W. Summers and Mr. R. P. Pillow as Ordinary Members.

8th June, 1948—

Papers.— (i) " *Eucalyptus oleosa*—The varieties and their oil yields in South Western Australia," by Mr. C. A. Gardner and Dr. E. M. Watson.
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1.—AN X-RAY STUDY OF WEST AUSTRALIAN BERYL.

By

K. NORRISH, B.Sc. HONS.
(University of Western Australia.)

Read : 12th August, 1947.

INTRODUCTION.

In recent years beryl has increased in importance in this State, mainly because of the use of beryllium in copper, acid resistant and other alloys. The mineral beryl, $Be_3\ Al_2\ Si_6\ O_{18}$, is the main source of beryllium.

Beryl is found in workable quantities in many areas of Western Australia. A study of Western Australian beryls is being made at the Government Chemical Laboratories and at the Geology Department of the University. The X-ray investigations described here were carried out in conjunction with these other studies.

The sample taken for X-ray investigation was from Yinnietharra (31°30′S. 121°35′E.) where one of the main occurrences of workable beryl in Western Australia is found (1).

EXPERIMENTAL.

Preliminary Observations.

The crystal studied was a clear transparent pale green of almost gem quality. The sample had no crystal faces or cleavage planes ; the surfaces consisted of concoidal fractures. It was brittle and hard.

The density was determined accurately by two methods. The first determination was made using a pycnometer while the second consisted in weighing a crystal in and out of water. In the second method, an empirical correction was made for the effect of the surface tension of water on the wire holding the crystal. In both cases corrections were applied to eliminate buoyancy and temperature errors. The methods used are described in the Dictionary of Applied Physics (2). The values found for the density were 2.713 and 2.715 gm. $cm.^{-3}$

Under polarised light the crystal was found to be optically uniaxial. The refractive indices were supplied by Dr. R. T. Prider of the Department of Geology of the University of Western Australia, as follows :—

For the ordinary ray (vibrations parallel to the lateral axes) $\omega = 1.5825$

For the extraordinary ray (vibrations parallel to the optic axis) $\epsilon = 1.5761$

Chemical Analysis.

The chemical analysis was carried out by Mr. H. P. Rowledge, Deputy Government Mineralogist, Government Chemical Laboratories, and appears in Table 1. The theoretical percentages on the basis of $Be_3\ Al_2\ Si_6\ O_{18}$ are also shown.

TABLE 1.

Chemical Analysis of Beryl.

	Actual Percentage.	Theoretical Percentage.
SiO_2	64.85	67.06
Al_2O_3	17.52	18.97
Fe_2O_3	0.37	....
MnO	0.01	....
MgO	0.14	....
CaO	*Nil*	....
BeO	13.15	13.97
Li_2O	0.52	....
Na_2O	0.94	....
K_2O	0.16	....
$(Rb\ Cs)_2O$	0.08	....
H_2O (given off above 105C.)	2.19	....
TiO_2	*Nil*	....
P_2O_5	*Nil*	....
Cr_2O_3	*Nil*	....
F	*Nil*	....
Cl	*Nil*	....
Total	99.93	....

Impurities occur in the crystal lattice by replacing ions of a similar radius. The structural formula is shown calculated in Table 2. It was calculated on the basis of 18 oxygen atoms per molecule, that is, it was assumed that the silicon tetrahedral structure is unaltered by replacements. The water is assumed to be present as OH^- ions replacing oxygen ions.

In the first column of Table 2 is listed the metals present, in order of increasing ionic radius. The ionic radii, taken from Evans (3), are shown in

TABLE 2.

Calculation of Structural Formula of Beryl from the Chemical Analysis.

Metals Present.	Radius of Metal Ion.	Weight.	Molecular Weight.	Molecular Proportions.	Number of Oxygen Atoms.	Number of Metal Atoms on the basis of 18 (O, OH).	
BeO	0.34	% 13.15	25.02	0.5260	0.5257	2.809	3
SiO_2	0.39	64.85	60.06	1.0797	2.1600	5.772 (0.191; 5.581)	6
Al_2O_3	0.57	17.52	101.94	0.1720	0.5160	1.840 (0.419; 1.421)	
Fe_2O_3	0.67	0.37	159.70	0.0023	0.0069	0.025	
MgO	0.78	0.14	40.32	0.0035	0.0035	0.019	
Li_2O	0.78	0.52	29.88	0.0174	0.0174	0.186	
MnO	0.91	0.01	70.93	0.0001	0.0001	0.001	1.836
Na_2O	0.98	0.94	61.99	0.0152	0.0152	0.162	
K_2O	1.33	0.16	94.19	0.0017	0.0017	0.018	
$(Rb\ Cs)_2O$	1.57 (average)	0.08	234 (average)	0.0003	0.0003	0.004	
H_2O	....	2.19	18.02	0.1215	0.1215	1.299	
	....	....	....	....	3.3683		

Structural formula is $(Be, Si)_{3.00}\ (Si, Al)_{6.00}\ (Al, Fe, etc.)_{1.836}\ O_{18}$.

Molecular weight calculated from the structural formula is 534.3 atomic weight units.

Column 2, with the percentages by weight in the next column. The molecular proportions of the metals (Column 5) were obtained by dividing their percentage weights (Column 3) by their molecular weights (Column 4). From the molecular proportions the total number of oxygen atoms are found (Column 6) and then the number of metal atoms per molecule are determined on the basis of 18 oxygen atoms. These last figures were found by dividing the number of oxygen atoms (3.368) into 18 and using this factor to multiply the figures in Column 5.

In some of the samples of beryl, water was present as minute inclusions (in tubes parallel to the *c* axis) but there was no evidence of the water being present as inclusions in the sample under consideration.

Optimum Thickness of Beryl for Use with X-rays.

It may be shown (4) that the optimum thickness of a sample for use with X-rays is $\frac{2}{\mu}$ where μ is the linear absorption coefficient of the sample for the X-rays being used. From the mass absorption coefficients for Be, O, Al and Si supplied in the Handbook of Chemistry and Physics (5), the mass absorption coefficient for beryl is calculated to be 32.45 $cm.^2$ $gm.^{-1}$, for CuKα radiation. This gives for the linear absorption coefficient 88 $cm.^{-1}$ and for the optimum thickness of beryl 0.2 mm.

Laue Diffraction Patterns.

To obtain Laue diffraction patterns a suitable crystal is set stationary with a crystal axis parallel to the X-ray beam. Having a crystal axis parallel to the X-ray beam simplifies the interpretation considerably. General radiation is used.

As mentioned earlier, beryl has a single optic axis ; this defines and is identical with the *c* axis. Using a geological microscope and a large crystal, the *c* axis was found and a plane perpendicular to this direction was ground and polished. As the crystal was too small to handle comfortably, it was ground after being cemented into celluloid. The grinding could only be carried out to within several degrees of the required direction. After polishiug the crystal was broken and a small piece, having one surface polished, was selected. This was then ground, preserving the polished surface, until the crystal was of the required dimensions (approximately 0.3 x 0.3 x 1.5 mm.).

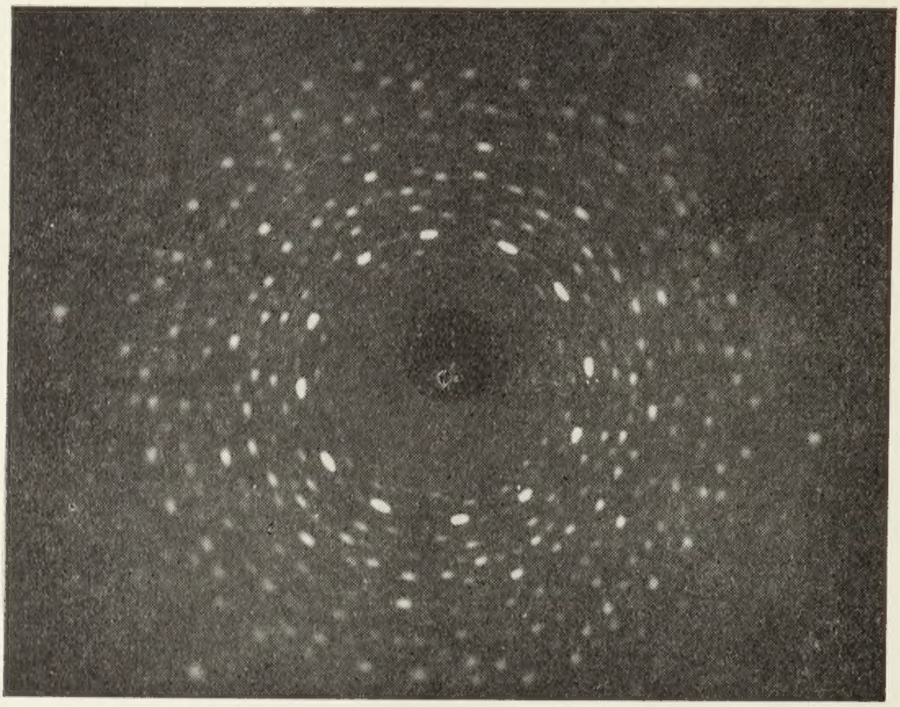
The crystal fragment was attached, using wax, to the needle point of the two circle goniometer. Previously the goniometer and spectrograph had been adjusted by optical methods using the telescope and collimator supplied with the Hilger unit.

To set the *c* axis parallel to the X-ray beam, a ray of light was passed down the X-ray collimating system and the crystal was adjusted until the polished surface reflected the light back through the collimator.

The crystal was then irradiated with general radiation, from a Coolidge tube operated at 60 kilo-volts and 5 milli-amperes. Under these conditions, using intensifying screens on both sides of the film, about four hours were required to obtain a well-exposed film but a half an hour's exposure was enough for preliminary patterns. The film was mounted in a flat container. The first pattern (see text fig. 9) was not symmetrical, indicating that the *c* axis was not parallel to the X-ray beam.

Adjustments and exposures were made until the crystal was set correctly to within 5′ of arc, this being the limit to which settings could be made on the goniometer arcs.

Readings on the goniometer arcs could be made to 10′ with the aid of the verniers. The film was then set at 5 cm. from the crystal by making two exposures with the film holder moved through a measured distance. By measuring the distances between corresponding spots on these two films, the movement of the film holder required to place the film 5 cm. from the crystal was



Text fig. 1.—Laue Diffraction Pattern Beryl with the X-rays travelling along the *c* axis.

calculated. All of these preliminary patterns were obtained using 1 mm. collimating pin holes to shorten exposure times. The final pattern was obtained with 0.5 mm. pin holes in the collimator. It is shown in text fig. 1 ; a slight asymmetry is detectable by accurate measurements of the diffraction spots.

The crystal was then adjusted until the line of symmetry in text fig. 1 that is inclined at 10° to the horizontal (the horizontal direction being the direction from left to right in the figure) was approximately parallel to the X-ray beam. This direction was subsequently established as being that of the *a* axis.

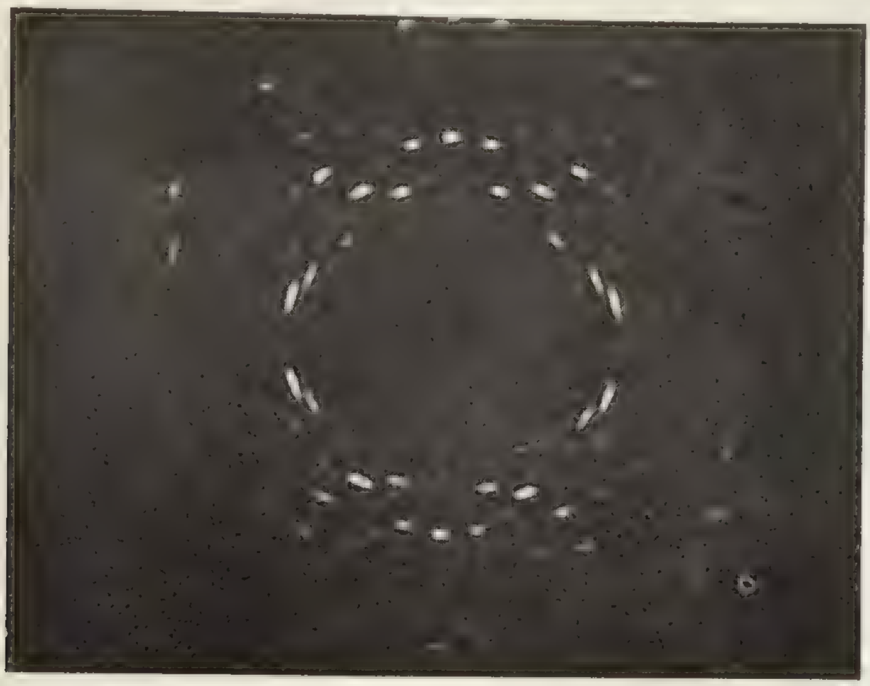
As with the *c* axis the final adjustments were made with the aid of exposures.

Text fig. 2 shows the resulting pattern.

Single Crystal Rotation Photographs.

To obtain these the crystal was first rotated about its *c* axis, and was irradiated with CuKα and MoKα radiations. The patterns were recorded on films placed in a cylindrical camera, the axis of the camera coinciding with the rotation axis of the crystal.

The same procedure was repeated to obtain a pattern for rotation about an a axis.



Text fig. 2.—Laue Diffraction Pattern of Beryl taken with the X-rays parallel to an a axis.

Text fig. 3 gives a reprint of the pattern obtained using $CuK\alpha$ radiation with the crystal rotated about its c axis.

Text fig. 3.—Diffraction Pattern of Beryl rotating about its c axis. (The fine horizontal lines were drawn in when measuring the negative.

From the reprint it can be seen that the diffraction spots are duplicated and that the layer lines are not straight. The duplication of the diffraction spots was due to the crystal being slightly out of adjustment, that is, the

rotation axis did not coincide with the axis of the crystal. The curvature of the layer lines was the result of the axis of the camera and the rotation axis, not coinciding.

Powder Diffraction Pattern.

A small piece of beryl was powdered by crushing between two hard pieces of steel, the beryl being too hard to be ground in an agate mortar. After crushing, an electro-magnet was used to separate out any pieces of iron. The powder was sieved through a piece of fine silk and then packed into a cylindrical sample tube. The sample was mounted on the spectrograph and a diffraction pattern recorded using CuKα radiation.

Text fig. 4.—Powder Diffraction Patern of Beryl.

RESULTS AND THEIR INTERPRETATION.

Symmetry.

All symmetry data were obtained from the Laue diffraction patterns. The Laue photograph taken with X-rays parallel to the *c* axis exhibits a six-fold axis of rotation and six lines of reflection. The pattern taken with X-rays travelling along the *a* axis has a two-fold rotation axis and two lines of reflection. These symmetry elements of the Laue patterns give beryl the diffraction symmetry 6/mmm (D_6h)*. With this diffraction symmetry, beryl must lie in one of the crystal classes (*see* references (6) and (7)):

6/m 2	(D_3h)
6 m m	(C_6v)
6 2	(D_6)
6/m m m	(D_6h)

These classes all give the same diffraction symmetry because Laue photographs always exhibit a centre of symmetry, irrespective of whether the crystal under consideration possesses one or not.

Unit Cell.

(a) *Parameters.*—The demensions of the axis of the unit cell were found, approximately from the single crystal rotation photographs, and then accurately from the results of the powder diffraction pattern.

From text fig. 3 it can be seen that the diffraction spots lie along straight lines, commonly known as layer lines. The layer line containing the direct beam is the zero layer line ; that on either side of this the first order layer line and so on.

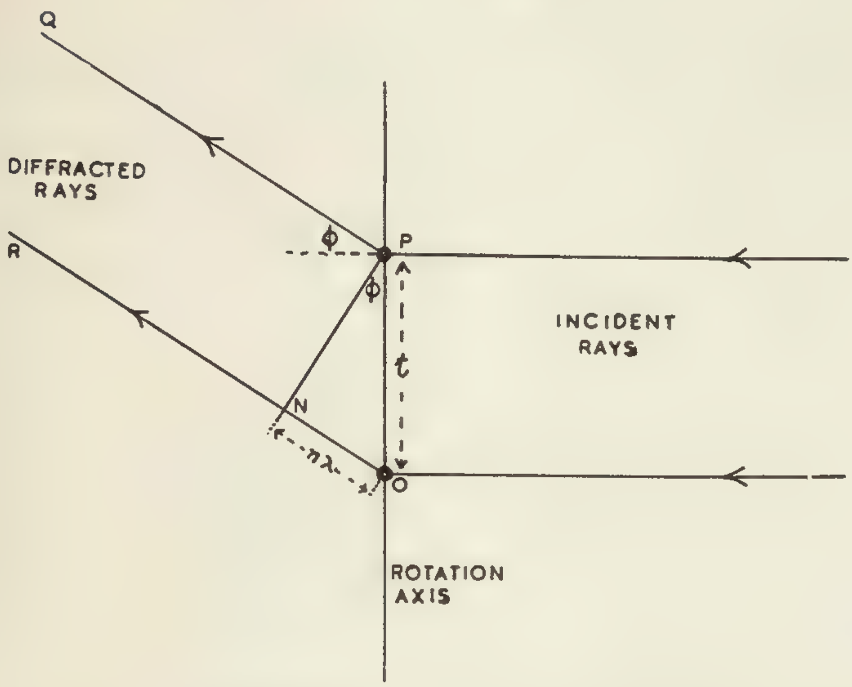
Text fig. 5 shows how the X-rays are diffracted by the rotating crystal. O and P are diffracting points, in the crystal, lying on the rotating axis.

t is the identity period along the rotation axis.

ϕ is the angle the diffracted beam makes with the horizontal.

n is the order of the layer line containing the diffraction spot.

* The internationally adopted symbols are used, but because many authors still use Schoenflies symbols, these are given in brackets.



Text fig. 5.—Diffraction of X-rays by a rotating crystal.

From the geometry of the figure it is obvious that when the diffracted beams from O and P are in phase so as to produce a diffraction spot on the fiim, then

$$n\ \lambda = t \text{ Sin } \phi \quad \ldots\ldots \quad (1)$$

λ being the wavelength of the X-rays.

If s is the distance of the nth order layer line from the zero layer line then

$$\text{Tan } \phi = \frac{s}{r} \quad \ldots\ldots \quad (2)$$

The radius r of the camera was measured mechanically corrections being applied for the thickness of the paper envelope and film. The corrected value of the radius was 3.32 cm.

When the rotation is about an axis of the crystal, then the identity period, t, becomes the length of the axis. The results and calculations for the c axis are given in Table 3.

TABLE 3.

Rotation about c axis. CuKα radiation.

Layer Line.	s in cm.	ϕ	c in A.U.
1	0.56	9°35′	9.24
2	1.19	19°43′	9.12
3	1.92	30° 3′	9.21
4	2.99	42° 1′	9.20

Average value of c = 9.19 A.U.

The value of c calculated from a photograph taken with MoKα radiation agreed well with the aforementioned value of c.

The value of the a axis, determined in a similar manner, gave an average value of 9.20 A.U.

To calculate the axial lengths accurately the lines of the powder diffraction pattern were measured and the interplanar spacing, d/n, of each line was calculated from Bragg's equation $n\ \lambda = 2d \text{ Sin } \theta$.

The most intense lines on the pattern were indexed graphically as described in Davey (8). The main lines were plotted on a logarithmic scale, the scale then being tried against each graph of the hexagonal system until a fit was obtained. This was found on the triangular close packed lattice graph at the point where the axial ratio was unity. The Miller indices of the larger spacings were read off direct from the graph. The higher orders of these lines were then indexed. The indices of the rest of the lines were found by trial and error, after a and c had been calculated, using the formula :—

$$d_{h\ k\ l} = \sqrt{\frac{4}{3a^3}(h^2 + k^2 + hk) + \frac{l^2}{c^2}} \quad \ldots \quad \ldots \quad (3)$$

Only those lines indexed graphically, and their higher orders, were used in the evaluation of the lattice parameters as in many cases several sets of indices were assignable to a line. The lines in Table 4 marked with an asterisk, were those used in the calculations. The methods used to calibrate the camera, eliminated errors due to film shrinkage and eccentricity, absorption being the only error left to be dealt with. The error $\triangle\ \theta$ in the Bragg angle due to absorption, is given by Buerger (9)

$$\triangle\ \theta = \mathrm{E}\ \mathrm{Cos}^2\ \theta.$$

where E is a constant depending on the degree of divergence of the X-ray beam. This gives (9) for the error equation

$$\left(\frac{n\ \lambda}{2\ d}\right)^2 = \mathrm{Sin}^2\theta - \mathrm{E}\ \mathrm{Cos}^2\theta\ \mathrm{Sin}\ 2\ \theta$$

which may be written

$$a\ \mathrm{D} = \mathrm{Sin}^2\theta - \varepsilon\ \mathrm{E}.$$

where $n^2 = a$, $\left(\frac{\lambda}{2d}\right)^2 = \mathrm{D}$ and $\mathrm{Sin}2\ \theta\ \mathrm{Cos}^2\theta = \varepsilon$.

The most probable value of D and therefore of d is given (9) by

$$\mathrm{D} = \frac{\begin{vmatrix} \Sigma\ a\ \mathrm{Sin}^2\theta & \Sigma\ a \\ \Sigma\ \varepsilon\ \mathrm{Sin}^2\theta & \Sigma\ \varepsilon^2 \end{vmatrix}}{\begin{vmatrix} \Sigma\ a^2 & \Sigma\ a\ \varepsilon \\ \Sigma\ a\ \varepsilon & \Sigma\ \varepsilon^2 \end{vmatrix}} \quad (4)$$

This gives the best value of the spacing, d, corrected for absorption errors. If the indices of the spacing are of the form ($h\ k$ O) or (O O l), then a *or* c may be determined directly from the application of formula (3).

For spacings whose indices are of the general form, ($h\ k\ l$) then a and c are determined by using two spacings, obtaining two equations from (3) to solve for a and c.

The calculations, using the above methods were long and laborious and are not shown here, but the values of the parameters were

$$a = 9.188 \text{ A.U.}$$
$$c = 9.189 \text{ A.U.}$$

The error in each case was certainly less than 0.01 A.U. and was probably about half of this. These results show that the chosen axis was the a axis.

TABLE 4.

Results of the Powder Diffraction Pattern.

Line.	Intensity.	$\theta°$	d/n A.U.	Miller Indices.
1	vw	5°	8.83	β of (100)
2	st	5°34′	7.93	(100)*
3	m	9°38′	4.60	(002)*
4	m	11°12′	3.96	(200)*
5	w	12°21′	3.60	β of (112)
6	st	13°42′	3.25	(112)*
7	m	14°48′	3.01	(202) (210)
8	st	15°37′	2.86	(211)*
9	vvw	16°54′	2.65	(300)*
10	m	17°51′	2.51	(212)*
11	w	19°39′	2.289	(220) (004)*
12	w	20°27′	2.203	(130) (104)
13	w	21° 3′	2.142	(213)
14	vw	22° 4′	2.048	(222) (114)
15	w–m	22°48′	1.986	(204) (400)*
16	vvw	23°36′	1.922	
17	vw	25° 0′	1.821	(230) (214)
18	w	25°33′	1.784	
19	w–m	26°22′	1.733	(140)
20	w	26°55′	1.700	(322) (411)
21	w	28°19′	1.622	(224)*
22	vw	28°58′	1.589	(500)*
23	vw	29°33′	1.561	(215) (702)
24	vw	30°15′	1.528	(330) (006)*
25	w	30°43′	1.507	(106) (404) (420)
26	w	32° 4′	1.450	(116) (332)
27	w	32°36′	1.429	(422)*
28	w	34°24′	1.362	(216)
29	vvw	35°24′	1.328	(306) (600)*
30	w–m	37°15′	1.272	(250) (226) (602)
31	w–m	37°45′	1.257	(251) (424)*
32	w–m	39°52′	1.200	(217)
33	vvw	40°54′	1.176	(523)
34	vw	42° 6′	1.148	(440) (008)*
35	vw	42°42′	1.134	(108) (700)*
36	vw	43°42′	1.114	(118) (442)
37	vvw	44°12′	1.104	(260) (208)
38	vvw	45°15	1.083	(336)*
39	vvw	45°51′	1.073	(426) (218)
40	vvw	46°15′	1.065	(353) (345)
41	vw	47°22′	1.046	(156)
42	vvw	48°30′	1.028	(444) (228)
43	vvw	49°30′	1.012	(451)
44	vvw	50° 7′	1.002	(630) (606)*
45	vw	50°39′	0.9951	(408) (800)*
46	vw	52°18′	0.9725	(270) (802)
47	vw	52°45′	0.9668	(219)
48	vw	53°30′	0.9572	(714)
49	vw	56°51′	0.9191	(550) (00, 10)*
50	vw	57°27′	0.9128	(460) (428)
51	vvw	58°42′	0.9005	(552)
52	vw	59°48′	0.8904	(813) (455)
53	vw	61° 6′	0.8790	(21, 10)
54	vvw	62°30′	0.8676	(280) (902)
55	vw	64°24′	0.8533	(22, 10)
56	vw	67°15′	0.8345	(636)*
57	vw	67°39′	0.8320	

* Lines used in determining lattice parameters.

N.B.—All the indices are expressed in the form ($h\ k\ l$). It has been a general practice with the hexagonal system to give the indices ($h\ k\ i\ l$) but as $i = h + k$, the author considered that the indices ($h\ k\ l$) were sufficient. h and k are interchangeable.

st = strong, m = medium, w = weak, v = very.

(b) *Number of Molecules per Unit Cell.*—Knowing the density of beryl, the weight of a molecule, and the volume of the unit cell, the number of molecules in a unit cell can be calculated.

The volume of a unit cell in the hexagonal system is

$$V = a^2\, c \sin 60 \qquad (5)$$

The density of beryl is given by

$$\rho = \frac{m\ M}{V} \qquad (6)$$

where m is the number of molecules per unit cell and M is the mass of a molecule expressed in grams.

Combining (5) and (6) we have

$$m = \frac{a^2\ c\ \mathrm{Sin}\ 60}{M} \qquad (7)$$

The experimental values of ρ, a and c and the value of M (table 2) reduced to grams, were used in (7) to give

$$m = 2.05.$$

Since the number of molecules in a unit cell must be integral, there are two molecules per unit cell.

Another way of viewing the above result is that, assuming two molecules per unit cell, the density calculated from X-ray data is 2.64 gm. cm.$^{-3}$. This agrees reasonably well with the experimental density. (Even with chemicals and elements of high purity, the discrepancies between the calculated and experimental densities are large.)

(c) *Confirmation of the Unit Cell.*—Because Laue diffraction patterns contain reflections from many planes, they are used to see if the chosen unit cell accounts for the observed reflections. Each set of planes in the crystal diffracts that wavelength in the X-ray beam that satisfies Bragg's Law. When the position of the crystal axes is known with respect to the X-ray beam, as in the present cases, then it is possible by calculation to find the Miller indices of the planes responsible for each diffraction spot.

The angle, θ, at which the X-ray beam meets the diffracting planes, is the sole factor governing the position of the diffraction spot (situated at 2θ) on the film. This means that the various orders of a particular spacing will all be super-imposed and that the resultant diffraction spot will be contributed to by several different wavelengths.

To index all the spots on Laue film, analytically, would be a tedious process so that the indexing was performed graphically by the gnomonic projection method. A gnomonic projection rule was made, as described in Wyckoff (10), from celluloid. The theory of gnomonic projection is shown in text fig. 6. X-rays strike the extended crystal plane RSTU at an angle θ. The direct beam registers on the film MNOP at C′ and the diffracted beam at F′. The gnomonic projection of the reflecting plane is G where GC is perpendicular to the plane RSTU. From the geometry of the figure it is seen that

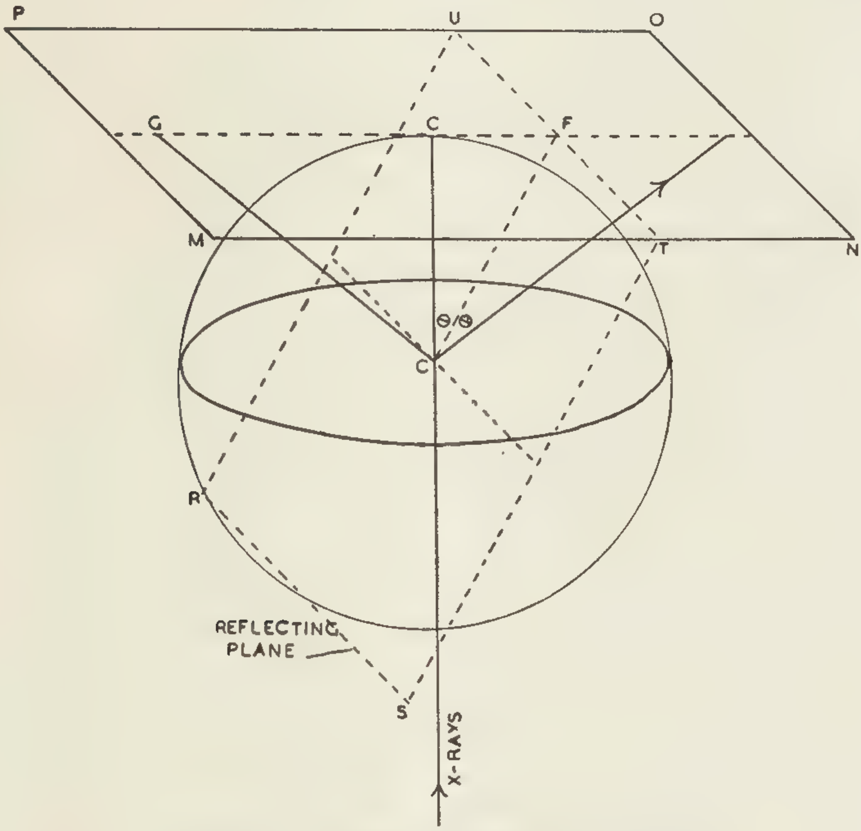
$$GC' = CC'\ \mathrm{Cot}\,\theta \qquad (8)$$

$$F'C' = CC'\ \mathrm{Tan}\ 2\theta \qquad (9)$$

The distance of the film from the crystal, CC′, was 5 cm., so that

$$GC' = 5\ \mathrm{Cot}\,\theta \ \text{ and } \ F'C' = 5\ \mathrm{Tan}\ 2\theta.$$

If the point F' is known it is possible to calculate the corresponding point G. The process is carried out graphically with the aid of a gnomonic projection rule, one side of which measures the distance $C'F'$ (the distance of the diffraction spot from the direct beam) while the other side is graduated in accordance with the requirements of equations (8) and (9) to give the projected distance GC'.



Text fig. 6.—Theory of Gnomonic Projection.

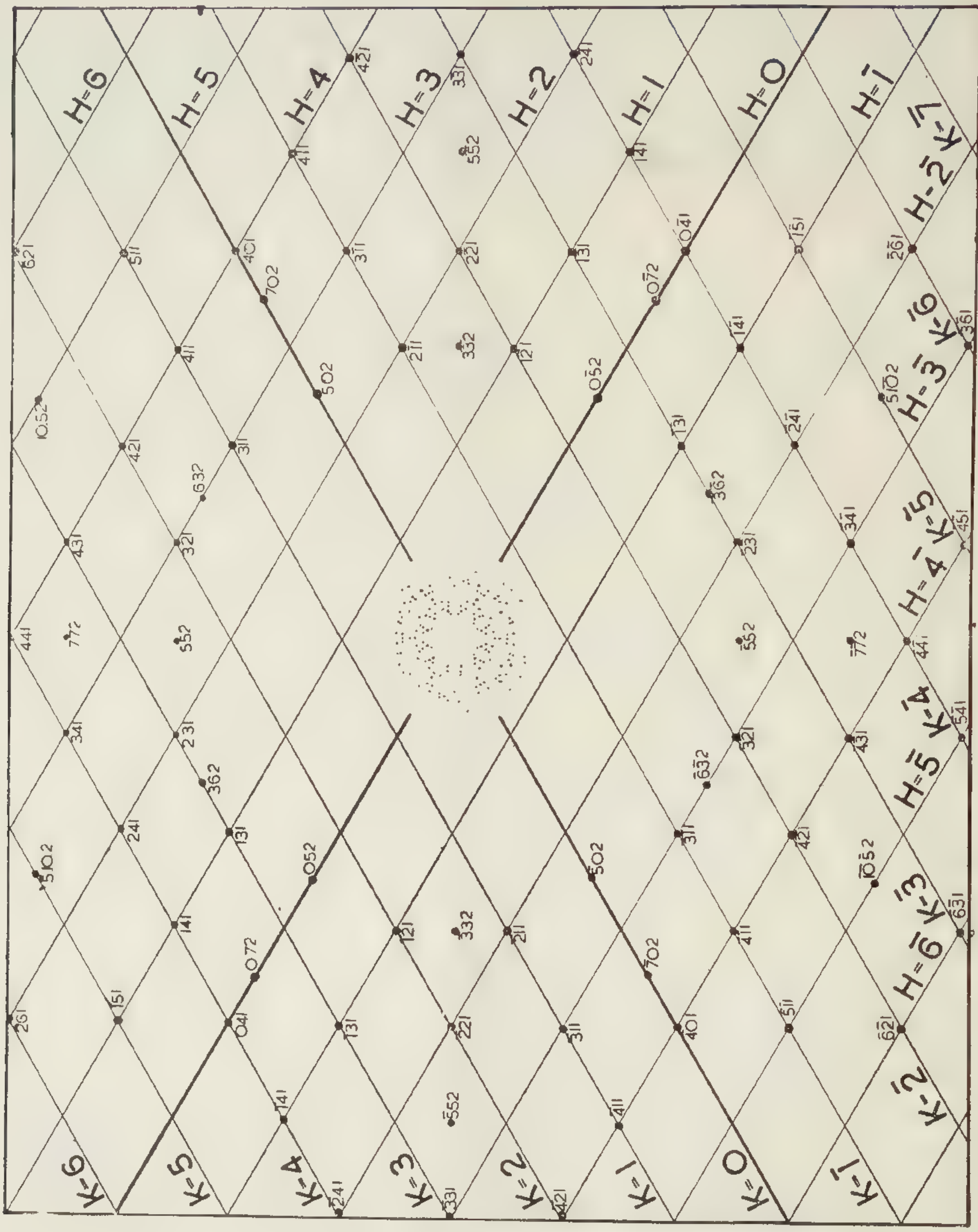
To carry out the gnomonic projection a co-ordinate system, see text fig. 7, was first drawn. For the Laue film with X-rays travelling parallel to the c axis, this consisted of two sets of parallel lines inclined at 60°, that is, the unit of the network was a rhomb with a 60° angle. It is easily demonstrated that the side of a rhomb is equal to

$$\frac{CC'}{\text{Cos } 30} \times \cdot \frac{c}{a}$$

giving 5.77 cm. for the case under consideration. The Laue photograph was placed on the network with the spot due to the direct beam at the intersection of two lines and with two of the a axes lying along these lines. The ruler was placed with its zero over the direct beam and the projection was carried out. This procedure was rapid and free from errors. The projected points lay on the corners of rhombs or simple submultiples of them. The Miller indices were read off direct from the chart, all the indices having $l = 1$.

In text fig. 7, for clearness, only a few of the spots are shown plotted.

The simplest method of judging whether the assumed unit cell accounts for the observed reflections is to compare the observed and predicted intensities of the Laue spots.



Text fig. 7.—Gnomonic projection of a Laue photograph of Beryl, X-rays travelling to *c* axis.

The maximum energy of an electron striking the target of the X-ray tube is

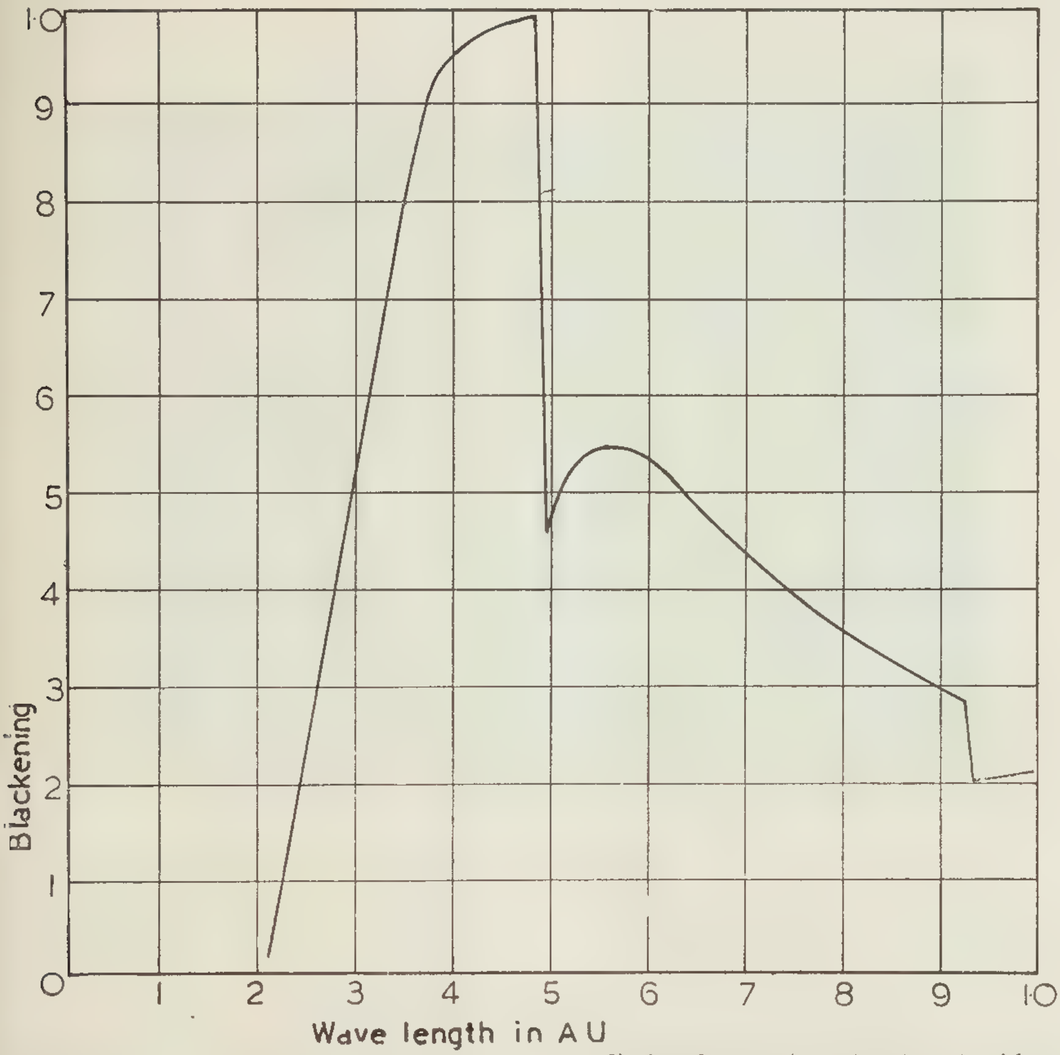
$$E_{max} = e\,V = h\,\nu = \frac{h\,c}{\lambda_{min}} \tag{10}$$

e	is the charge on the electron,
V	is the potential difference between the electrodes of the X-ray tube,
h	is Planck's constant,
ν	is the maximum frequency of the X-rays,
λ_{min}	is the minimum wavelength present,
c	is the velocity of light.

For an applied voltage of 60 kilovolts we have

$$\lambda_{min} = \frac{h\,c}{e\,V} = 0.21 \text{ A.U.} \tag{11}$$

Text fig. 8 shows a graph obtained by plotting wavelength against the blackening effect on the film. No radiation is present with a wavelength of less than 0.21 A.U. but its intensity rises rapidly from 0.21 A.U. to reach a maximum at approximately $2\lambda_{min}$ (0.48 A.U.). The discontinuity at 0.48 A.U. is due to the critical absorption edge of silver being at 0.48 A.U. The bromine in the film emulsion causes the other discontinuity in the curve at 0.92 A.U.

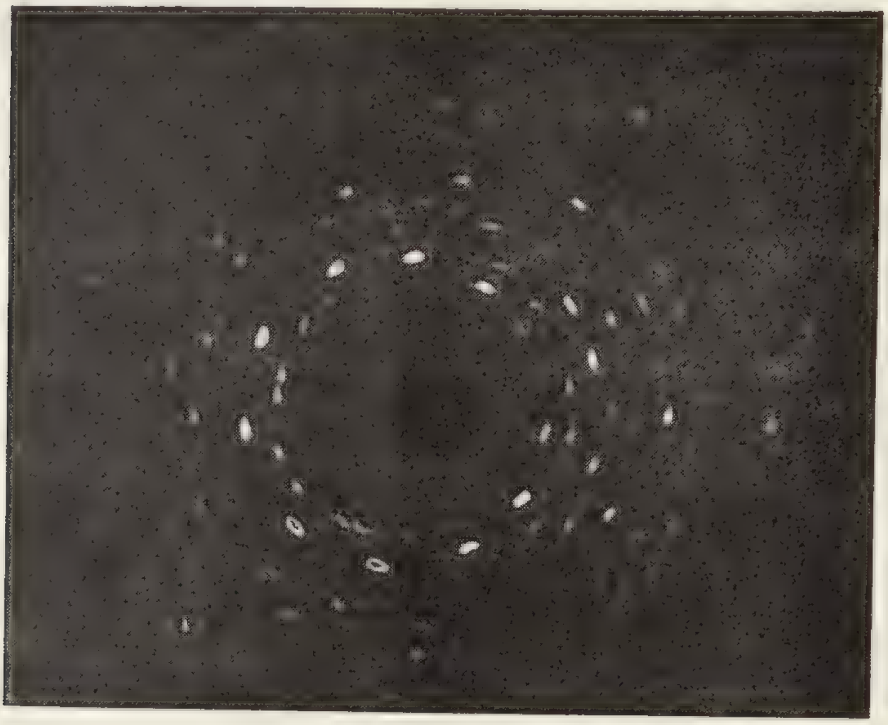


Text fig. 8.—Photographic effect of a white radiation from a tungsten target with an applied voltage of 60 Kilovolts.

By applying Bragg's Law to a diffraction spot whose Miller indices are known, the wavelength producing the spot may be calculated ; d/n is calculated from the crystal parameters using equation (3) and θ is determined from the distance of the spot from the direct beam. This applies only to those wavelengths between λ_{min} and $2\lambda_{min}$, that is, between 0.21 and 0.42 A.U. Spots, due to fundamental spacings, and wavelengths of less than $2\lambda_{min}$, are the result of one wavelength only as there is no wavelength present that is short enough to be diffracted by the higher orders of the spacing. Spots with $n\lambda > 2\lambda_{min}$ may be contributed to by several different wavelengths due to higher orders.

In plotting a graph of wavelength against blackening on the film, only planes of the one form (that is, planes with the same diffracting power) may be used. On a Laue photograph with X-rays travelling parallel to an axis,

all the spots due to planes of the same form have the same θ and consequently are due to the same wavelength. In this case, the various spots would be coincident on a graph. To obtain a photograph in which the diffraction spots, due to planes of the one form, have different θ's, an exposure was made with the X-rays making an angle of several degrees with the c axis. This Laue photograph is shown in text fig. 9; it was taken during the setting of the crystal. The spots on this pattern were indexed by a visual comparison with those of text fig. 1, whose diffraction spots had been indexed.



Text fig. 9.—Laue Pattern of Beryl with the X-rays making an angle of several degrees with the c axis.

The intensities of the spots were estimated visually from the negative.

Text fig. 10 shows the points plotted on a graph. No significance was attached to those points whose wavelengths were greater than 0.44 A.U., in confirming the unit cell. The curve shows the correct minimum and maximum wavelengths with the silver absorption edge at the correct position.

Space Group.

Standard treatises on crystallography place beryl in the holosymmetric class of the hexagonal system (6/mmm). This is in agreement with the data given earlier in the section on Symmetry.

A study of the spacings present and absent on the powder diffraction pattern, shows the absence of the following classes of reflection, $(h\ 0\ l)$ and $(h\ h\ l)$ in cases where l is odd. The extinction of the $(h\ h\ l)$, l odd, reflections indicates a $(1\ \bar{1}\ 0)$ glide plane of component $c/2$: the extinction of the $(h\ 0\ l)$, l odd, reflections implies a (0 1 0) glide plane of component $c/2$ (11). The diffraction symbol for beryl now becomes 6/mmm C/cc. Knowing that beryl belongs to the crystal class 6/mmm, the space group is C6/mcc ($D_{6}^{2}h$) (12).

No attempt was made to place the atoms of beryl within the unit cell.

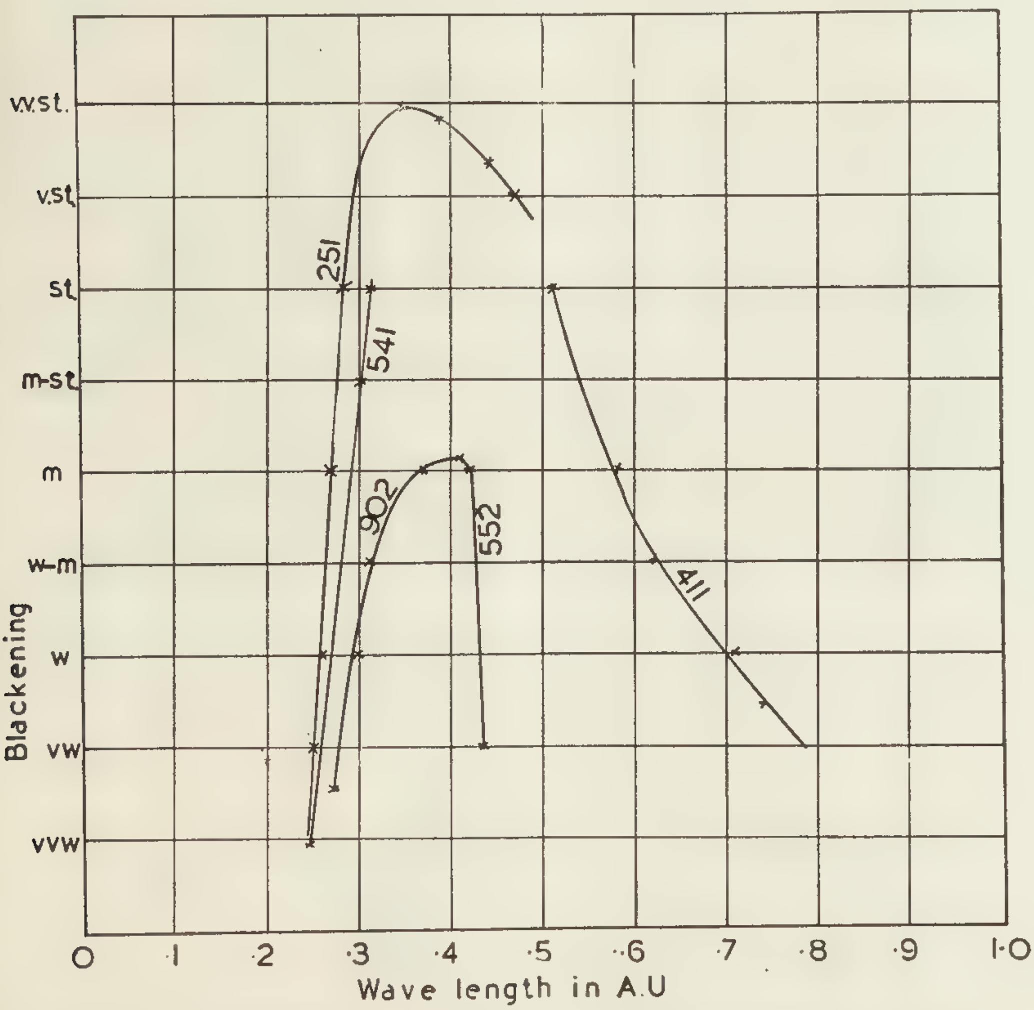
Bragg and West (13) have made a complete analysis of the structure of beryl. All of the above results are in accord with their conclusions. They give the lengths of the crystal axis as

$$c = 9.17 \pm 0.01 \text{ A.U.}$$

and

$$a = 9.21 \pm 0.01 \text{ A.U.}$$

The variation in the lattice parameters is probably due to the impurities contained in beryl.



Text fig. 10.—Experimental curve showing the blackening effect of X-rays.

SUMMARY.

The Laue, the single crystal rotation and the powder methods of X-ray analysis were used to study a crystal of Western Australian beryl. The techniques and methods of interpretation, associated with the different methods, are described.

The results obtained are in agreement with the other published data on beryl.

ACKNOWLEDGMENTS.

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Dr. R. T. Prider of the Department of Geology of the University and Dr. D. Carroll of the Government Chemical Laboratories suggested the work and the author is indebted to them for supplying the samples together with optical and chemical data on beryl.

Mr. J. Shearer of the Department of Physics of the University of Western Australia supervised the work and the author is grateful to him for his guidance and assistance in the experimental work and for his advice concerning the preparation of this article.

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2.—SOME OBSERVATIONS OF SOLAR RADIOFREQUENCY RADIATION.

By

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Read : 12th November, 1947.

1. INTRODUCTION.

The emission of radiofrequency radiation from the Milky Way was first observed many years ago (1), but the emission of such radiation from the sun was not definitely detected until toward the end of the war when equipment developed for radio location was adapted for measurement of the solar radiation at various frequencies for comparison with the values theoretically predicted from blackbody laws. Whilst the results of measurements at the highest frequencies did not differ greatly from those predicted for a surface solar temperature of 6,000°C., at frequencies from 30 to 500 Mc/s the radiated energy, especially when large sunspot groups were visible, was found to be hundreds of times the expected values.

The observations described in this paper were made between May, 1946, and October, 1947. When they were started it was known that the energy radiated from the sun at frequencies of about a hundred megacycles per second increased with sunspot area, and especially with meridian passage of large sunspot groups (2), but nothing was known of possible correlations with other transient visible solar phenomena such as chromospheric flares. Some of the conclusions resulting from these observations were reached independently by other observers, on whose work information was subsequently received. In such cases acknowledgment is made in the course of discussing the results.

During this period, theoretical understanding of the processes in the solar atmosphere giving rise to the radiofrequency radiation was also advanced (1, 3), and these contributions are taken into account in discussion on the source of the noise radiation at the conclusion of this paper.

2. APPARATUS.

By the courtesy of the Director of the C.S.I.R. Radiophysics Laboratory at Sydney the author was loaned two 75 Mc/s radar receivers. With assistance from the staff of the laboratory design data for a Yagi aerial, consisting of a folded half-wave dipole, reflector and two directors, was obtained for 65 Mc/s and scaled up to the operating frequency. An aerial constructed to this design was mounted on a crude polar axis (without automatic drive) and provided with movement in declination. The elements were so oriented that horizontally polarized radiation was observed. Although maximum sensitivity in the forward direction is desirable, construction difficulties at 75 Mc/s are formidable for any but the Yagi type of aerial and ability to detect anything but marked emission was sacrificed for portability and simple, cheap construction.

The noise factor of the receiver, measured in the Radiophysics Laboratory, was about seven. Two years later it was measured in the Physics Laboratory of the University of W.A. and found to be nine. It cannot be assumed that this characteristic did not change during operation, and this together with the lack of appropriate apparatus for assuring accurate balancing of the aerial to receiver and for measuring more than very crudely the effective gain of

the aerial in the forward direction, prevented any serious consideration of absolute values of received power. In the beginning the variable elements of the aerial, lengths of dipole, reflector and directors were adjusted for maximum sensitivity to horizontally polarised radiation from a transmitter mounted about a hundred yards distant on a flat roof. Reflection from the roof interfered with efforts to obtain a polar diagram.

At first visual, and later photographic observations, were made of the variation of the anode current of the second detector. The linearity of this detector to input voltage was confirmed by laboratory tests and care was always taken that receiver gain was decreased sufficiently to ensure that only in exceptional cases would the maximum load current of the detector be reached. Observation of receiver noise current (I_N) using a dummy aerial load at the input, and of the receiver noise plus solar noise current (I_{S+N}) when connected to the aerial, was used to determine received solar noise.

If the set noise input power is W_N and the solar noise input power W_S then $I_N^2 = CW_N$ and $I_{N+S}^2 = C(W_S + W_N)$

(C being a constant for the linear detector)

$$(I_{S+N} - I_N)^2 = I_{S+N}^2 + I_N^2 - 2I_{S+N} I_N$$

$$= CW_S + CW_N + CW_N - 2C\sqrt{(W_S + W_N) W_N}$$

$$= CW_S - 2C W_N(W_S + W_N - W_N)$$

$$\text{So } CW_S = (I_{S+N} - I_N)^2 + 2C\sqrt{W_N}(\sqrt{W_S + W_N} - \sqrt{W_N})$$

$$= (I_{S+N} - I_N)^2 + 2I_N(I_{S+N} - I_N)$$

$$W_S \infty (I_{S+N} - I_N)(\overbrace{I_{S+N} - I_N} + 2I_N)$$

Where $I_{S+N} - I_N$ is the height of the disurbed trace above the undisturbed level. This expression was used when accurate measurement of the solar noise power was required, as for example in examining the shape of the pulses (*see* Section 5).

Initially photographic recording of the " grass " pattern of a Cathode ray oscillograph was attempted, the trace being moved along the X-axis and observed as it passed behind a narrow slit parallel to the Y-axis. By using the synchronous motor driving the camera to close a circuit and light a pea-

lamp behind the slit, a time mark was put on the film every 75 seconds. While this system showed up violent short-period disturbances it could not provide any useful indication of the magnitude of solar-plus-set noise current and was soon replaced by a more satisfactory method.

A portable Tinsley vibration galvanometer with a suspension unit designed for operation on 50 cycles was modified by (a) detuning it to resonate at about 45 cycles compared with the local power frequency of 40 cycles, (b) altering the optical system to provide a small spot instead of an extended disk on the scale, (c) shunting the coil so that the sensitivity was about 16 mm. per millampere D.C. and the damping such that the spot came to rest after a sudden deflection in about 0.25 seconds, and (d) adding series resistance to make up the correct load in the anode of the detector.

By means of reflection in two 90° prisms the horizontal deflection of the galvanometer spot was changed to vertical deflection at the camera lens. The image on the film was reduced about three times. A simple camera box using 35 mm. film passing over a sprocket driven by a synchronous motor was constructed in the laboratory workshop. Film speed was about 12.15 mm./minute, or about 10 feet for a normal, daily, four-hour run. A properly focused and exposed trace allowed resolution of consecutive peaks occurring within two seconds and it was found feasible to project the films with magnification about 30x, under which conditions the centre of the trace could be determined with a linear accuracy corresponding to 0.25 second.

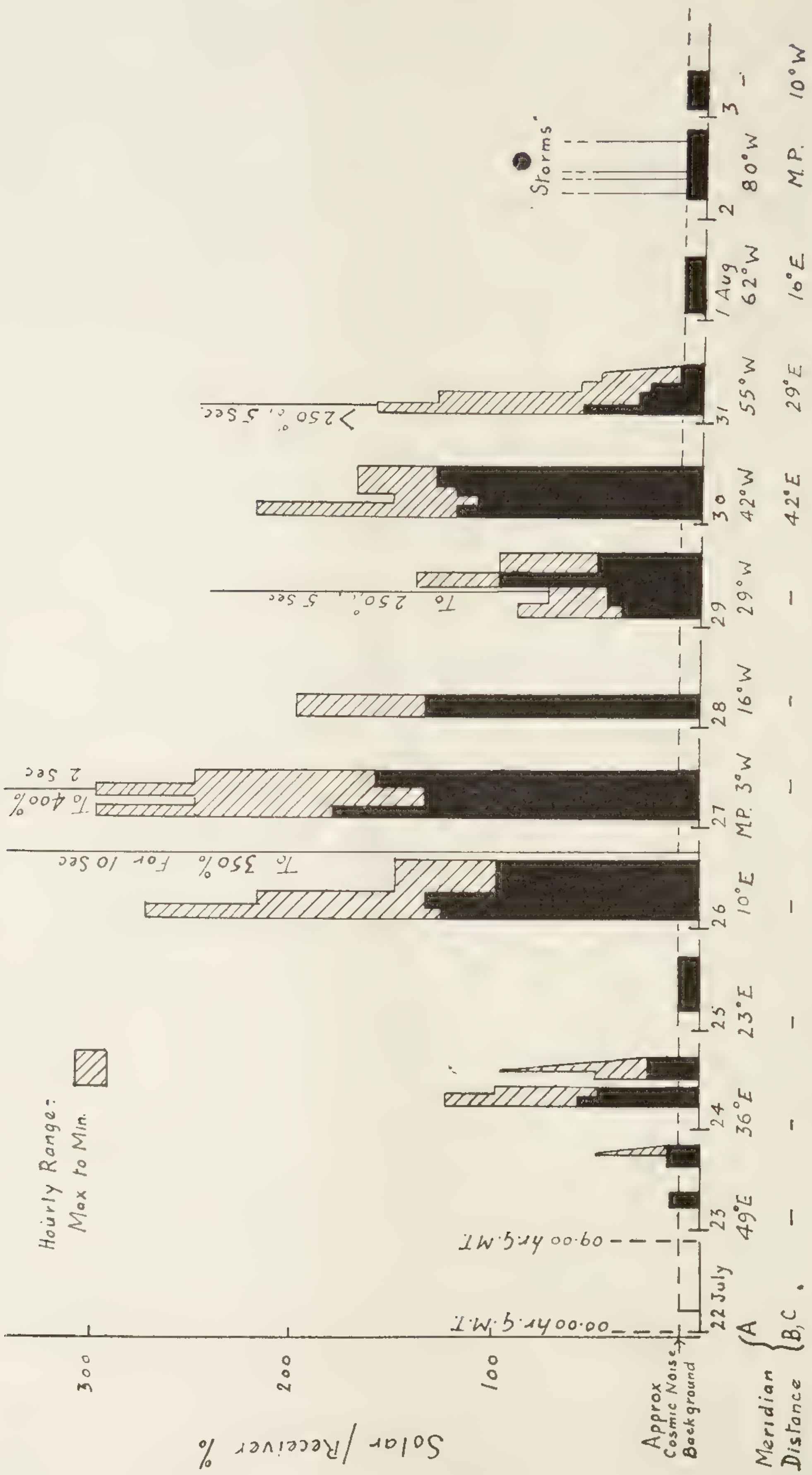
No serious attempt was made to photograph either time marks or a scale of ordinates on the film. Time marks were made about half-hourly by connecting the set input to a dummy load for thirty seconds and subsequently disconnecting the galvanometer for a similar interval to record the zero line. When ordinates were required the film was suitably projected onto a ruled screen.

In initial tests the cosmic radiofrequency radiation was used as a source. An increase of about 20 per cent. was observed in noise current as the aerial was turned towards the centre of the galaxy from the galactic pole. The apparatus was at that time set up on the flat roof of Hackett Hall at the University of W.A. with a clear horizon except for 30°N. and S. of W. In 1947, the apparatus was moved to a site in the University grounds with a clear horizon from the East through North to West, but the Southern horizon was obscured by the building housing the receiver and a spectrohelioscope as well as by trees. No attempt was made to use the cosmic radiofrequency flux level as a calibrating source, since site errors would have been too serious.

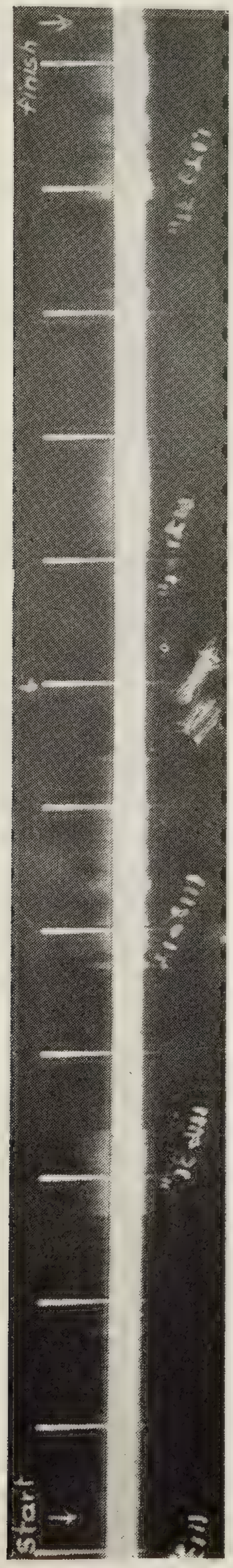
The sensitivity of the apparatus was such that under quiet conditions the trace was quite flat showing no continuously varying deflection characteristic of the more sensitive receiving systems used on 200 Mc/s. An advantage of the vibration galvanometer is its distinctive response to interference. Ignition noise, switching, power frequency hum characteristic of diathermy apparatus, etc., is shown by marked blurring of the record due to the widened trace. This can be very easily distinguished from solar noise variations.

3. OBSERVATIONS OF JULY–AUGUST, 1946.

The first significant observations were made during the passage of two large sunspot groups between 20th July, and 3rd August, 1946. Some of the conclusions from these observations have already been recorded [4]. Continuous observations were maintained for from three to five hours each day, during the



Text Fig. 1.—Solar Noise Level Perth, W.A. Hourly Ranges 75 Mc/s 22/7/46 to 3/8/46.



Text Fig. 2.—Disturbance observed on 2nd August, 1946, 03.14 U.T. to 03.29 U.T.

The time marks are 45 sec. apart.

passage of the large sunspot group A, situated in Lat. 24°N., Long. 197°, with mean meridian passage on 1946 July 26.7 (G.M.T.) and the two following groups, B and C, situated in Lat. 9°N., and 29°S. and Long. 110° and 108°, with mean meridian passages on August 2.25 and August 2.4 respectively. These observations are plotted in text fig. 1.

The following conclusions were reached regarding the nature of solar radiofrequency radiation :—

(i) For convenience, solar radiofrequency noise can be divided roughly into two types, the one "steady" or relatively slowly variable (Component I), the other abruptly variable (Component II).

That a similar distinction had independently been made by McCready, Pawsey and Payne-Scott (5), came to the author's notice at a much later date.

While Component I. is possibly the statistical resultant of a large number of processes whose fundamental mechanism is the same as that giving rise to Component II., the actual developments causing the emission of the two types must differ considerably in many respects and significant distinctions have been found (*see* Section 7).

Component I. was very strong during the passage of group A across the solar disk. Its existence was postulated as a result of examining the ratio of maximum to minimum solar-plus-receiver/receiver noise obtained during each successive full hour's observation. In twenty-eight hours spread over ten days, there were only four hours during which this ratio exceeded two, three of these occurring on 31st July. Excluding fluctuations to higher levels occurring for but one or two seconds, which were observed on a relatively small number of occasions, no variations comparable with those observed on 2nd August (*see* below) were seen.

(ii) Component I. can be emitted from a spot region which is showing no marked activity when observed with the spectrohelioscope. For example, on July 28–30, the flocculi associated with group A were diminishing in intensity according to spectrohelioscope observations made at Watheroo Magnetic Observatory, but the noise was still very high.

(iii) The strength of Component I. cannot be related simply to the passage of the spot across the central meridian. In text fig. I. are shown the relative levels observed on 13 successive days, maximum and minimum values being indicated. The higher noise levels were observed when the group was West of the meridian. The level was also higher on 24th July and 30th July, than on the adjacent days when the meridian distance was less.

(iv) The magnitude of Component I. is apparently dependent on some as yet unidentified activity over the spot area itself, possibly associated with the previous occurrence of solar flares. In contrast to group A, groups B and C, which were of much greater than average area, showed no significant emission of Component I. when on and to the West of the central meridian, group A having rounded the West limb. The noise observed on 31st July was, therefore, attributed to group A. No exact information is available with regard to the flocculi associated with the two later groups, though it is understood that these spots were less active than group A. The level of Component I. does not appear to correlate simply with spot number or area.

(v) The variable Component II. changes by very large amounts in one or two seconds. A striking example observed on 2nd August is shown in text fig. 2, a reproduction of the film record of the cathode ray trace. From comparison with two less intense, but similar disturbances, which were recorded on both meter and film, it is estimated that this " storm " involved increases in noise power by 50 to 100 *times* in a second or two. The width of the undisturbed trace indicates the normal noise mean amplitude, which included solar noise amounting to about 10 per cent. of that from the receiver. During most of the disturbance the trace extended beyond the limits of the stop over the oscillograph screen, which implied an increase in amplitude of the trace of two to three hundred per cent. Timemarks occur every 75 seconds and intervals of three seconds can be resolved. The abrupt variations are totally different from any solar phenomenon observed visually. Close examination of the original record shows that the more intense bursts of radiation consist of separate peaks spaced on the average 2.5 seconds apart. Their apparent width is dependent on the width of the slit covering the oscilloscope screen.

4. OBSERVATIONS MARCH–SEPTEMBER, 1947.

During the period March-September, 1947, an effort was made to record during the period 10.00–14.00 hour local time, on five days each week. About 450 hours' recording was made on 126 days.

Based on the observations of July-August, 1946, disturbances were classified according to duration with, initially, an arbitrary limit of five minutes for those to be classed as Component II. Three disturbances observed in May and June, which were similar in duration to those observed on 2nd August, 1946, were of a nature conflicting with this arbitrary criterion. At the same time they were judged from their high flux level particularly, to be physically distinct from the normal short-lived disturbances and evidence given in the next section regarding their correlation with visually observed solar changes supports this conclusion.

Of the 126 days, on only five certainly, on one doubtfully, and for three short periods of less than an hour each, was radiation of the type Component I. observed. Of these days two pairs were on consecutive dates. Apart from the short periods, of which two are doubtful, Component I., when observed, was very marked throughout the observing period. A characteristic record was always produced. Sunspot conditions on the five days are described below.

The high level of noise on 10–11th March was undoubtedly connected with the central meridian passage of the large spot group on the 10th. On the 12th, the level was back to normal. No observations were made in the seven days preceding 10th March.

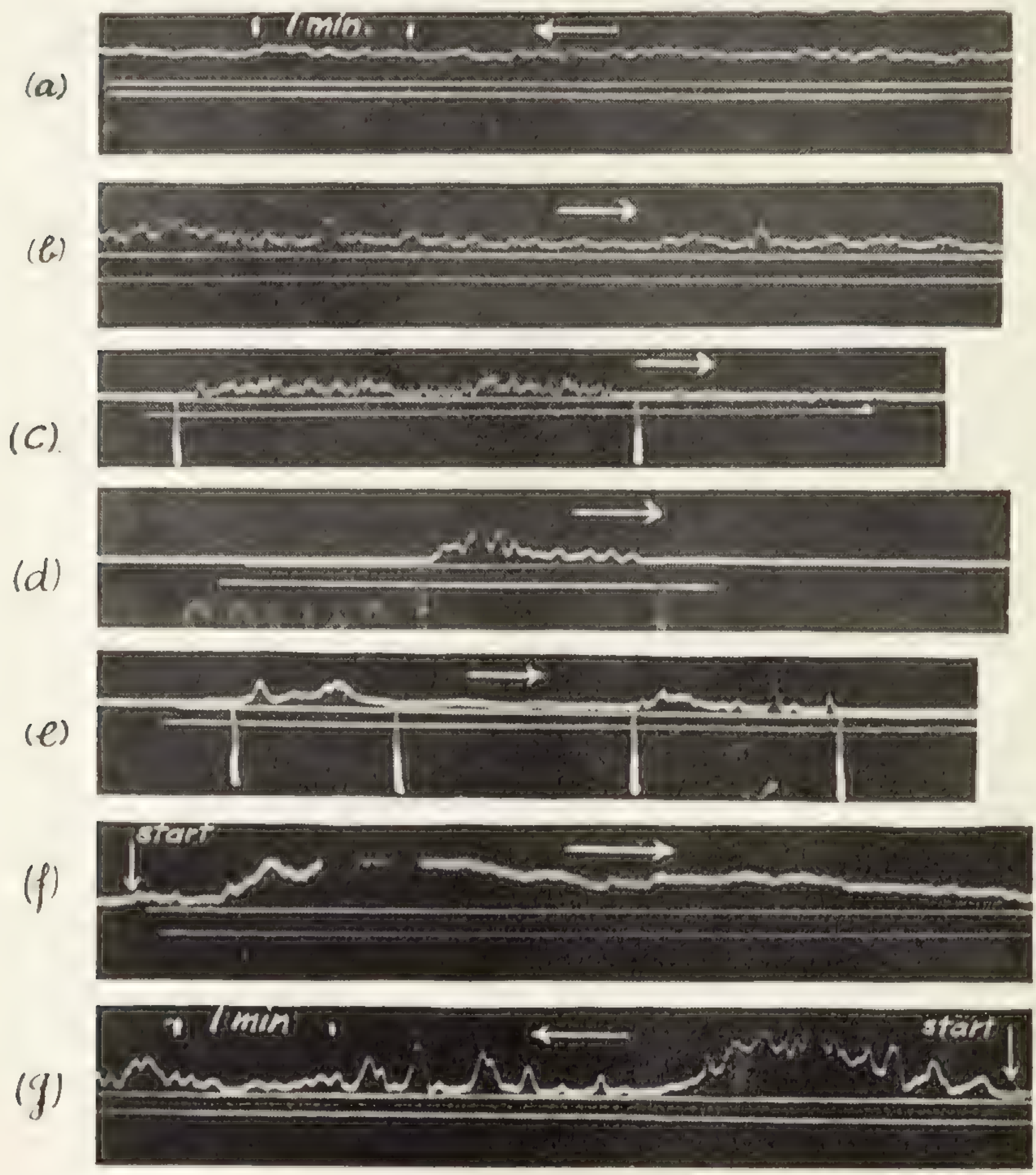
On 10th and 12th June there was no abnormal noise, although it was observed on 11th June. Group 8611 (Mt. Wilson) crossed the central meridian on 9th June.

Only small sunspots were near the centre of the disk on 20th June with central meridian passage June 22.0.

On 25th September, when a large active bi-polar group, Mt. Wilson No. 8823, crossed the meridian no type I. radiation was observed, although radiation of this type was observed for two hours on the previous day and the whole of the following day. The radiation level was not at all high, but the frequency of occurrence of pulses was at times very high.

The conclusion of Section 3, namely, that the level of type I. radiation does not depend essentially on meridian passage is supported by these observations. The fact that large sunspots passed over the disk on several occasions without producing an appreciable increase in the level shows that sunspot area is likewise not the essential factor.

Disturbances classed as Component II. were observed on 74 of the 126 days and numbered 250, or about one per hour for disturbed days or one per two hours for all days. The average duration of these disturbances was about one minute, though they range from single peaks lasting ten seconds or less, to a series of ten or more, lasting nearly five minutes.



Text Fig. 3.—Examples of solar noise records. The position of the galvanometer spot for zero current and for receiver noise current is indicated by the straight lines. The arrows show the direction of time. (a) 10/3/47: Type I with high level background. (b) 26/9/47: Type I with low level background. (c) 27/5/47: Short lived Type I, 0331-0335, U.T. (d) 3/9/47: Type II, 0219-0221 U.T. (e) 27/5/47: Type II, 0508-0512 U.T. (f) 16/5/47: Large Type II disturbance, 0328-0337 U.T. coincident with large flare. (g) 30/9/47: Part of large Type II disturbance, 0236-0248 U.T.

On five occasions in addition, were observed disturbances of exceptional intensity classed as Component II., but of average duration 12 minutes and consisting in part at least of overlapping peaks superposed on a high flux level. The two disturbances observed on 2nd August, 1946 (0314–0329 G.M.T. and 0451–0457½ G.M.T.), could also be classed in this group.

Examples of the various types of disturbances are illustrated in text fig. 3.

In no case, on records of either type of disturbance was there observed such an abrupt change of flux level that the galvanometer, in following, left no photographic record. In other words, increase or decrease of radiation flux from base to peak or vice versa was never observed as occurring in an interval less than about one second, although the galvanometer was capable of following changes occurring fifty times faster. This characteristic became in fact the chief criterion for rejecting as spurious apparent disturbances observed occasionally and subsequently traced at times to operation of a laboratory oscillator. This aspect of the records is discussed in more detail in Sections 6 and 7.

From the 450 hours' observation it is concluded that sustained noise (Component I.) is observed rarely, depending on the presence near the centre of the disk of large and active sunspots ; that short bursts of pulses lasting about a minute (Component II.) are comparatively frequent, with a tendency to concentration on disturbed days and that violent short-lived disturbances, such as that illustrated in text fig. 2, are comparatively rare.

5. CORRELATION OF NOISE DISTURBANCES WITH VISIBLE SOLAR PHENOMENA AND IONOSPHERIC FADEOUTS.

In the latter of the two periods of observations discussed (1947), chromospheric flares or ionospheric fadeouts almost certainly resulting from flares, were reported from Canberra, Kodaikanal or Watheroo Observatories on forty occasions when noise records were available. A partial analysis of the data has already been published. ([6]).

On twelve of these occasions, including nine flares of importance, 1, 2 flares of importance 2 and one noise storm observed on 200 Mc/s. of a type considered to be simultaneous with a flare, no noise disturbances were recorded on 75 Mc/s. during the four hour observing period in which the solar disturbance occurred.

On only one occasion (16th May, 1947) was there observed simultaneous occurrence of flare and 75 Mc/s. noise. The flare (Kodaikanal, importance 3) started at 0329 U.T. with a maximum brightness at 0337 and ended at 0342. A violent noise disturbance started at 0328, continuing till 0338.

Two other violent disturbances were recorded nearly simultaneously with ionospheric fadeouts and noise disturbances on 200 Mc/s. observed at Canberra and thought to coincide with flares. These were :—

4th June, 1947.—Canberra fadeout, 0300–0445 U.T., 200 Mc/s. noise 0304-8 ; Perth 0310–32 violent noise.

5th June, 1947.—Canberra fadeout 0220–0330, 200 Mc/s. noise 0237–9, 0302–8 ; Perth 0237–0302 violent noise.

There were nine occasions when one, or a few, medium to small pulses were recorded during a fade or flare. On five other occasions simultaneity was doubtful or the noise was very slight. On three occasions in addition to the twelve first mentioned there was no simultaneous noise.

It would seem that only with large flares can simultaneous noise production be expected with reasonable probability. Since Component II. disturbances are observed on the average hourly on disturbed days, the above results do not indicate much more than chance coincidences.

The 1946 observations provided interesting material on 2nd August. The disturbances shown in text fig. 2 started at 03h. 14m. 10s. (approx. G.M.T.) and finished at about 03h. 29m. 10s. The report on spectrohelioscope observations supplied from Watheroo Magnetic Observatory, reads :

> "Aug. 2. Conditions clear. Observing times : 00 : 45 GMT to 01 : 00 GMT, 03 : 15 GMT to 03 : 30 GMT, 05 : 00 GMT to 05 : 15 GMT. Observations made between 00 : 45 and 01 : 00 showed that the various spot groups were not active and the flocculi about these spots were rather faint. Between 03 : 15 and 03 : 30, while scanning the sun's disk, it was noticed that a bright prominence (intensity 1) had appeared on the N-W limb above the leading spot group. This prominence appeared to be of the active type known as "eruptive prominence." It was also noticed that the flocculi about the spot group were active. By 03 : 30 the prominence had faded considerably. None of the other groups showed activity and the flocculi were faint."

A similar, but less intense disturbance, during which the milliameter showed increases in solar/receiver noise from 10 per cent. to more than 150 per cent.—the pointer left the scale for a few seconds—was recorded on the same day between 04h. 51m. and 04h. 57m. 30s. (G.M.T.). Ionospheric equipment at Watheroo recorded a fadeout of intensity 4 (scale 1–9) from 04h. 45m. to 05h. 00m. The Watheroo spectoheliosccope report reads :

> "At 05 : 00 a rather faint prominence was seen over the spot group on the N-W limb. In appearance it was similar to the prominence seen at 03 : 00 but appeared narrower and made up of vertical streaks. By 05 : 07 this prominence had disappeared. The flocculi about the spot group appeared to be active."

Similar disturbances recorded on the same day, from 03h. 59m. to 04h. 04m. 10s. and 07h. 27m. to 07h. 30m. were not accompanied by fadeouts and the sun was not under observation at Watheroo.

It has not been possible to check whether noise disturbances of Type II. occur when no flare is observable since the observing hours for spectrohelioscopes were not supplied. However, reasonable assumptions as to the period of use of spectrohelioscopes before and after observation of recorded flares and the non-appearance of ionospheric fadeouts, indicate that pulses of radiation do occur outside the times of recorded flares.

Whereas only once was noise radiation observed to precede a flare and then possibly noise of Type I. rather than Type II., on twelve occasions noise followed a flare with less than 30 minutes delay and on seven other occasions subsequent noise was either delayed longer, or was very slight. Only on 4th June, 1947, and 5th June, 1947, in addition to the twelve occasions when noise was nil, was no subsequent noise observed.

In view of suggestions (3) that noise originates in the lower corona as a result of plasma oscillations excited either by ultraviolet light or corpuscular bombardment, delayed as well as simultaneous noise might be connected with a flare. It is to be expected that excitation by ultraviolet radiation would presuppose increased emission in Hα, i.e., a flare, at the same time as the ultraviolet emission increases. If corpuscles excite the plasma oscillations they may or may not originate from a flare. If they do come from a flare, the interval between flare and noise will depend on their velocity and the height in the corona at which the excitation takes place. Observations supporting this view have already been published (7).

Phenomena involving corpuscular emission, such as aurorae and magnetic storms following the meridian passage of large spots can occur independently of flares, so that the assumption that corpuscular emission causing plasma oscillations can also occur without observation of flares would not be novel. The observation of 2nd August, 1946, namely a violent noise storm lasting 15 minutes, occurring as an eruptive prominence was seen to develop from an active area suggests corpuscular excitation of the corona as a possible mechanism.

Since 75 Mc/s radiation received at the earth cannot have penetrated electron densities greater than about 108/cc. in the solar atmosphere, noise generated by radial emission from centres a considerable distance from the central meridian would only be received in exceptional circumstances. This consideration might explain why two flares of importance 2, occurring 60E. and 61W. of the central meridian respectively were not associated with noise. It would not explain why one flare of importance 2, 4°E. and three flares of importance 1 occurring less than 15° from the central meridian were not associated with noise.

6. SHAPE OF PULSES OF TYPE II. RADIATION.

During the 1947 observations, single pulses of radiation of Type II. clear of overlapping pulses were observed on about 100 occasions. In view of the ability of the recording galvanometer to follow changes in noise current much more rapid than those actually observed, it was considered reasonable to accept the galvanometer trace as a true record, taking into account the linear detector, of the variation of radiated power with time. Interest in this question was stimulated by the observation of a number of large single pulses having very marked "tails", which looked as though they might obey some ascertainable law of decrease.

The "tail" of the pulse indicates the manner in which the source of radiation falls off in radiating power. The simplest case is that of a source possessed of a certain energy by reason of its oscillations and receiving no energy from outside. If the rate of decrease of energy in the oscillations and hence of radiation of energy is proportional to the energy in the oscillations, the power-time curve will follow an exponential law, $P = P_0 e^{-xt}$. The energy loss need not be exclusively by radiation so long as the relationship holds. Collision damping might be involved for instance.

Suitable pulses were therefore projected with a magnification about 30x and the centre line of the photographic trace of the film was recorded at a scale of one inch to four seconds. The measured ordinates were then converted to relative power levels by using the formula given in section 2 and their successive ratios at constant intervals of time (0.4, 0.5 or 1.0 sec.) were examined for variation about a mean value. The smaller this variation, the nearer to exponential is the curve.

Of 132 tracings made, 28 were rejected as poor curves due to the presence of small overlapping pulses and five were fronts of pulses only. Of the remainder, 21 were good curves, but the height of the pulses was small, less than 25% of the set noise background and the length of falling slope was considered too short to provide a worthwhile result. The remaining 78 were then classified according to their approach to exponential form. A variation of 15% or less about a mean value of the exponent was taken as satisfactory and 58 came within this category. These were then assumed to be very probably exponential. Eleven were less probably exponential, four probably not so and five definitely not so.

As examples of the first, second and fourth categories, pulses Nos. 72, 26 and 76 are quoted :—

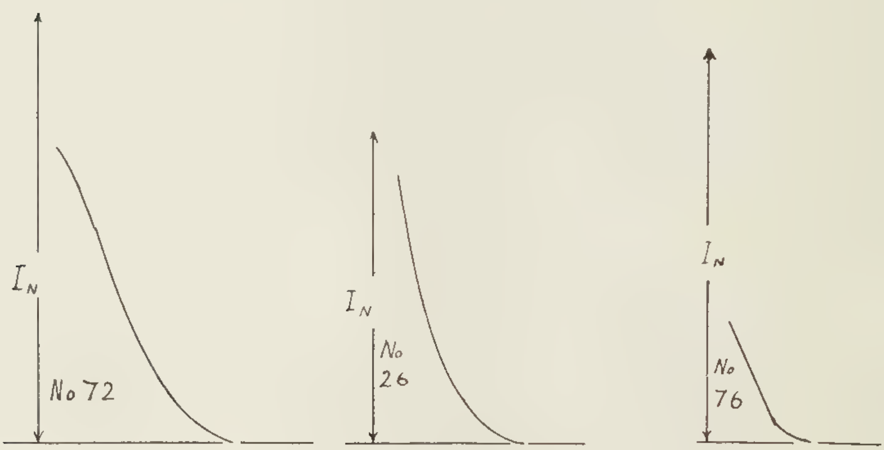
Pulse No.	Measured ordinates (0.4 sec. intervals).
72	20.5, 18.0, 15.2, 13.0, 10.6, 9.0, 7.0, 5.0, 4.0, 3.0, 2.2, 1.6
Power Ratios	1.19, 1.24, 1.17, 1.33, 1.21, 1.34, 1.46, 1·28, 1.36, 1.35, 1.43.
Exponential	Mean 1.30 ± 0.8 half-life 1.05 sec.

Pulse No.	Ordinates (1.0 sec. intervals).
26	29.7 (?), 20.0, 10.4, 5.1, 2.0.
Ratios	1.74, 2.31, 2.29, 2.76.

Doubtful if exponential.

Pulse No.	Ordinates (0.4 sec. intervals).
76	9.7, 7.3, 5.1, 2.9, 1.4, 0.7.
Ratios	1.39, 1.50, 1.85, 2.14, 2.04.

Not exponential.



Text Fig. 4.—Tails of Pulses, Nos. 72 (exponential), 26 (doubtfully exponential), and 76 (not exponential). I_N=Set noise current.

Between three quarters and nine-tenths of the curves reproduced in text fig. 4 were examined.

TABLE 1.

Half Lives of Exponential Pulses.

Half-life (sec.)	0.4—0·6	0.6—0·8	0.8—1·0	1.0—1·2	1.2—1·4	1.4—1·6	1.6—1·8	1.8—2·0	2.0—2·2	Over 2·2
No. of pulses	5	8	12	13	8	7	3	0	2	*Nil*

The times taken for the radiated power to decrease to half in the 58 pulses assumed to have exponential form, are set out in Table 1. It will be seen that the range of half-lives has definite limits and tends to concentrate about a value of one second. It is the task of theory to relate this result to the conditions in the region of the solar atmosphere where the noise is generated. Whether the variation in half-lives is attributable to a varying density of protons relative to electrons or to some other factor such as the distribution

of electron density in the region about the source can only be decided when considerable theoretical advances have been made. When this question has been clarified, observation of the half-life should provide valuable information regarding the solar atmosphere.

Pulses occurring consecutively or within a short interval may or may not come from the same source or region. If they do, similar half-lives are to be expected. Thirty such pulses were of interest from this viewpoint and they are listed in Table 2.

TABLE 2.

Half-lives of Consecutive Pulses.

27–5–47	30 sec.	(con.)	0.75, 0.65
4–6–47	30 sec.	(con.)	1.4, 0.9
22–7–47	30 sec.	(con.)	0.9, 0.9
23–7–47	1 min.	(con.)	1.2, 0.85
25–7–47	30 sec.	(con.)	1.1, 1.1
7–8–47	30 sec.	(con.)	0.7, 0.8
7–8–47	30 sec.	(con.)	0.8, 1.3
12–8–47	40 sec.		1.2, 1.75, 1.35
30–9–47	5 min.		1.0, 0.85, 0.9, 1.0, 0.5, 1.1
30–9–47	1 min.		0.9, 1.05, 1.0
30–9–47	30 sec.	(con.)	1.7, 1.1
30–9–47	30 sec.		0.9, 1.8

There are seven instances of differences greater than 0.3 sec., which is considered to be above the limits of error, as against nine (if the first four pulses of 30. 9.47 are counted as three instances) of agreement within 0.1 sec. x. The proportion of differing half-lives is too great to provide firm support for a conclusion that only one source covering a limited region is responsible for radiation at any given time.

Eight pulses, including the six consecutive pulses on 30. 9.47 occurred in disturbances which were judged to be of a type and magnitude probably coincident with solar flares, though no flare reports confirm this assumption. Their half-lives do not differ significantly from the remainder.

Since the rising portions of several pulses were suitable for magnification, tracing and analysis, an attempt was made to interpret two of them in terms of exponential functions, with no resulting success. This is not surprising since the influence of any exciting agent may at the initiation of radiation be varying in an unknown manner.

Attempts to analyse pulses occurring in Type I. radiation are discussed in the next section.

7.—DISTINCTIONS BETWEEN TYPE I. AND TYPE II. RADIATION AND THE NATURE OF TYPE I. PULSES.

The initial classification of two components made in 1946 on the basis the period for which a high level is sustained was not adequate for the more informative records obtained in 1947. A characteristic of Type I. radiation appeared to be the superposition on a more or less high level of small, brief, pulses occurring more frequently than those observed in the Type II. disturbances. The observation of 10–3–47 showed the presence of these pulses in conjunction with a very high background level. The Type I. observed on 20–6–47 and 26–9–47 was characterised by these pulses in conjunction with a relatively low general level. Since the observation of the pulses with or without high background constituted evidence of a long continued

disturbance, this characteristic assumed dominant importance in classifying the nature of the disturbance. Hence pulsing of similar type observed for short periods, for example for ten minutes on 25–7–47, was classified Type I. rather than Type II. Similar distinctions have been made by C. W. Allen ([8]).

While therefore the presence, or otherwise, of a high background level is of importance and indeed has been made a basis for distinction between radiation conditions, this section deals primarily with the distinction between the types of pulsing characteristic of the two types of disturbance.

One of the first investigations was of the duration of the pulses at the level of half maximum power. In this connection 208 pulses occurring in Type II. disturbances were measured as to duration and maximum power and, similarly, 178 pulses occurring on 10–3–47 and 11–6–47 in Type I. disturbances. This was done by projecting with up to 30x magnification. In the case of the latter type of pulses accuracy is low owing to the width of the trace on the film being of the same order as the pulse height.

The results are plotted in text fig. 5, the individual values for Type II. and the limits and average values only for Type I. being shown. A plot of the relative energy emitted in the pulses is shown in text fig. 6. It is clear that Type I. pulses are in general markedly distinct in appearance from Type II., although there is overlap in actual values observed.

The pulsing frequency is also different. The frequency of Type I. pulses averages from 10 to more than 20 per minute, while Type II. pulses average from 4 to 10 per minute.

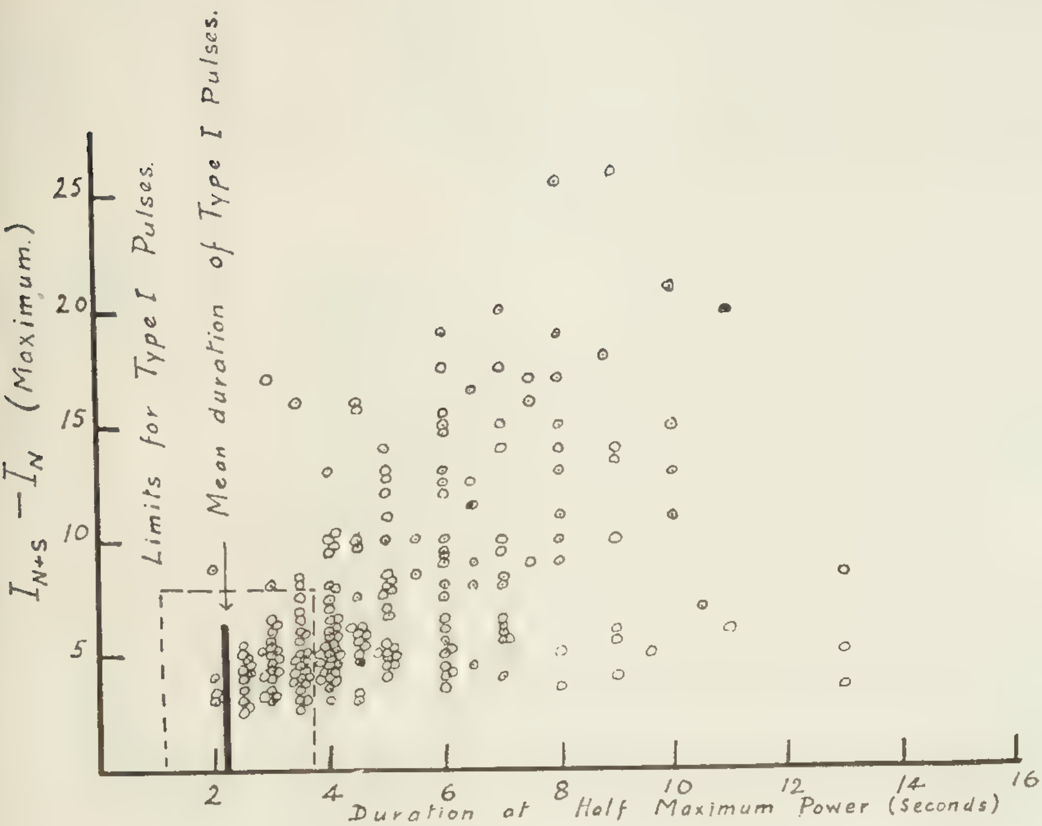
A further point of interest is the decay curve for Type I. pulses. Here again satisfactory accuracy is unattainable in most cases, since few pulses are suitable for tracing and the length of falling trace is usually too short for analysis by the method of section 6.

This was not the case for the record of 26–9–47 from which 21 pulse tracings were analysed by converting the ordinates to a scale of power. It is not possible to judge whether or not the curves are exponential, but they are assumed to be so in what follows. Making the assumption that the foot of the traced portion was the true zero for the pulse, the mean half-life of 21 pulses was determined as 0.4 sec. with extreme limits 0.25 sec. and 0.5 sec.

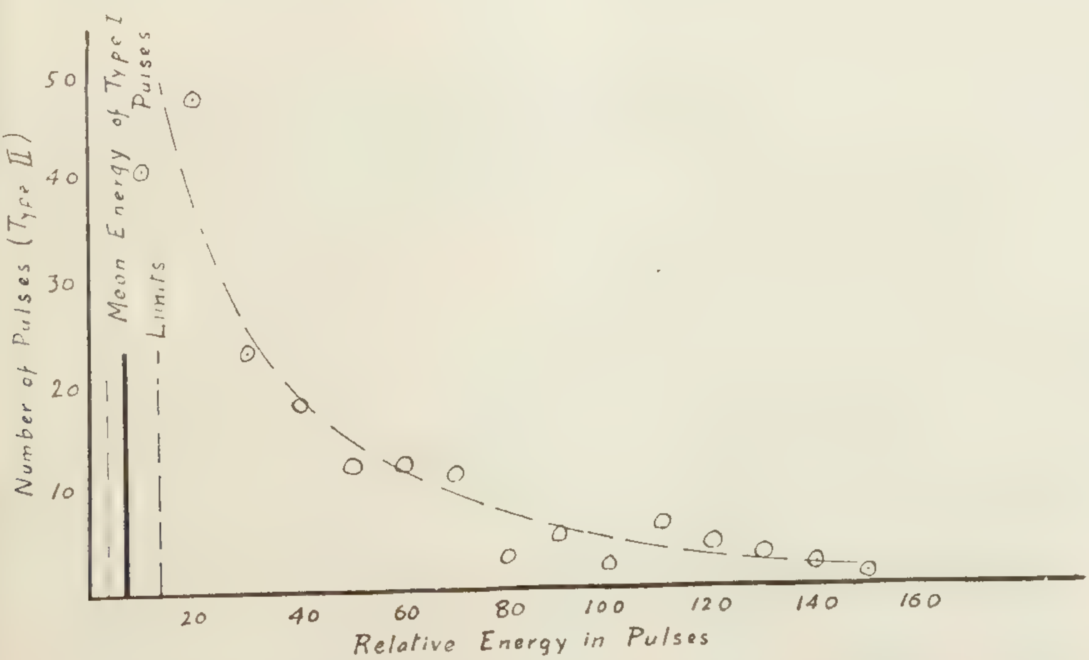
It is important to determine whether this result is significant, or whether it is due to the assumption that the pulses *as observed* are the *actual* pulses emitted instead of the result of overlapping of pulses having a considerably lower baseline, *e.g.*, the line I_N. If the latter assumption is made for the record of 26–9–47, the pulse half-lives will be increased about three times to an average of about 1.2 sec., or the same order as Type II. pulses. The range of half-lives, however, is from 0.35 sec. to 3.0 sec., which is wider than the observed range of Type I. pulses.

Other Type I. pulses could not be analysed in terms of power and an estimate of half-life could only be made by determining from the unconverted trace the time interval over which the ordinate decreased to half. It is found by comparison with the correct method of analysing traces, that this approximation overestimates the half-life by from 30–50%, depending on the values of I_N and I_{N+S}.

For nine pulses observed on 25–7–47 the mean half-life was about 0.55 sec. (uncorrected for overestimate) with limits 0.3–0·7 sec. assuming true pulses observed above a general background. If the tops of overlapping pulses were actually being observed the mean life (uncorrected) is about 0.9 sec. with limits 0.5–1.2 sec.



Text Fig. 5.—Values of duration at half maximum power for Type I and Type II Pulses.



Text Fig. 6.—Comparison of Energy in Type I and Type II Pulses.

Six pulses observed on 20–6–47 treated as true pulses yield a mean (uncorrected) of 0.5 sec. with limits 0.3–0·8 sec., as against a mean for overlapping pulses (uncorrected) of 1.7 sec. with limits 1.3 to 2.0 sec.

Finally two pulses traced from the record of 10–3–47 yielded a mean (uncorrected) of 0.6 sec. if taken as superposed on a high background and a rough mean about 3 sec., if overlapping pulses. The results are collected in Table 3, in which all values, except those of 26–9–47, were reduced by 30% to allow for the crude method of approximation.

TABLE 3.

Date.	No.	Superposed Pulses.		Overlapped Pulses.	
		Mean sec.	Limits sec.	Mean sec.	Limits sec.
10–3–47	2	....	0.4–0.45	....	about 2.0
20–6–47	6	0.35	0.2–0.5	1.1	0.8–1.4
25–7–47	9	0.35	0.2–0.5	0.6	0.3–0.8
26–9–47	21	0.4	0.25–0.5	1.2	0.35–3.0

Note.—The estimated half-lives have been reduced by 30% to allow for the crude method of measurement.

In the case of the record of 10–3–47 the general level was so high that the appearance on it of individual pulses gave a strong impression that they were true pulses of radiation occurring above the background. In the other cases while they give an impression of superposed pulses rather than overlapping pulses, it cannot be said that the result of assuming the record to consist of overlapping pulses yields half-lives grossly inconsistent with those obtained for Type II. pulses, and, as a consequence, this interpretation rather than the conclusion that half-lives of Type I. pulses are on the average considerably shorter than Type II. pulses cannot be ruled out. Additional experimental evidence is highly desirable on the question. The conditions under which pulses of radiation are emitted more frequently and for much longer intervals than in the short period disturbance are undoubtedly connected with the influence of large active sunspots on the overlying solar atmosphere and a higher than normal proton density, magnetic field and electrical conductivity would be expected.

The large Type II. disturbances of 16–5–47, 4 and 5–6–47 and 30–9–47 all show pulses characteristic of Type I. disturbance intermixed with and often superposed on large Type II. pulses. The differences in duration and frequency of occurrence of the two types are very marked. All these pulses are superposed on a relatively slowly varying background which attains a level comparable with the height of the pulses within about 30 seconds of the start of the disturbance.

8.—CONSIDERATIONS REGARDING THE SOURCE OF RADIO FREQUENCY NOISE.

When noise is observed to occur simultaneously with visible solar disturbances, the noise, in contrast to the $H\propto$ emission, begins very abruptly, rising to a high level in a matter of seconds, whereas the $H\propto$ emission increases over a period of as many minutes. Since in such cases increased ultraviolet emission is assumed to be responsible for both visible and noise emission, it is evident that the noise increases much more abruptly than the exciting agent. This can happen only if the emission of noise results from the development of oscillations in a region of the solar atmosphere whose normal equilibrium has been upset by the gradually increasing influence of the exciting ent.

If this view is rejected in favour of the idea that the emission of noise follows closely the magnitude of the exciting agent, then it must also be assumed that short pulses of ultraviolet light and also of corpuscular emission occur at reasonably regular frequencies of the order of ten to twenty per minute. No other observations of solar phenomena support this view. In addition, the exponential mode of decay of emitted noise power, if a direct reflection of the decay of the exciting agent would be much harder to understand than on the basis of the assumption made in Section 6.

More than one type of noise radiation is observed to be emitted during disturbances believed simultaneous with solar flares. It is also observed that Type II. disturbances appear superimposed on Type I. emission, as for example on 10–3 47. It appears then, that, under the influence either of greatly increased ultraviolet radiation during flares, or of the corpuscular or electromagnetic radiation presumably responsible for the high level of emission over large and active sunspot groups more than one region of the solar atmosphere can be excited to emission of solar noise. These regions would presumably be at different heights in the solar atmosphere, electron densities, magnetic fields and proton densities being different for each.

9.—ACKNOWLEDGMENTS.

I desire to thank Professor A. D. Ross for his continued interest in, and support of this work ; the Director of the C.S.I.R. Radiophysics Division and members of his staff for the loan of receivers and for much helpful advice and discussion ; Messrs. P. Hands, B.Sc. ; P. Jeffrey, B.Sc. and E. Denton, B.Sc. for assistance in taking observations ; Mr. H. S. Spigl, West Australian Government Astronomer, for heliographic data ; the Directors of the Commonwealth Observatory, Canberra, Watheroo Magnetic Observatory and Kodaikanal Observatory for solar and ionospheric data ; and Messrs. D. W. Everson and R. Wright of the Physics Department technical staff for assistance in design and construction of much of the apparatus. The research was assisted by a Commonwealth Research Grant.

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3.—THE GEOLOGY AND GEOMORPHOLOGY OF POINT PERON, WESTERN AUSTRALIA.

BY

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Read, 13th April, 1948.

CONTENTS.

I.—INTRODUCTION.

Point Peron (also known as Cape Peron*) is situated at 32° 15′S. by 115° 42′E. on the West Coast of Australia, about 15 miles S.S.W. of Fremantle. It was named by de Freycinet in 1803, in honour of Francois Péron who was a naturalist to the French expedition under Baudin, which explored the western coasts of Australia in the " Géographe " and " Naturaliste " between the years 1800 and 1804.

The following quotation from the journal of M. Louis Freycinet is taken from Peron and Freycinet (1807–16, Vol. 2, p. 194) ; " Le 10 mai, à midi, je me trouvois à peu de distance d'une pointe saillante et très aigue, que je désignai sous le nom de Cap Péron." Near here Freycinet hoped to pass

*There is a second Cape Peron in Western Australia, in Shark Bay (Lat. 25° 31′S., Long. 113° 30′E.).

between the islands and the mainland and so to the mouth of the Swan River, but an attempt to do so soon involved him in "les plus pressans perils." Eventually, "A 5 heures du soir, la brise s'éleva et je me hâtai de fuir en doublant les récifs par le Sud." The islands here (Garden I., Rottnest, Carnac, etc.) were named as a group "Les Iles Louis Napoleon," during this expedition, though the term has fallen into disuse.

Geologically and geomorphologically, Point Peron and vicinity does not yet appear to have been accorded any detailed scientific description or mapping, with the exception of a short note on the lime possibilities by Miles (1945).

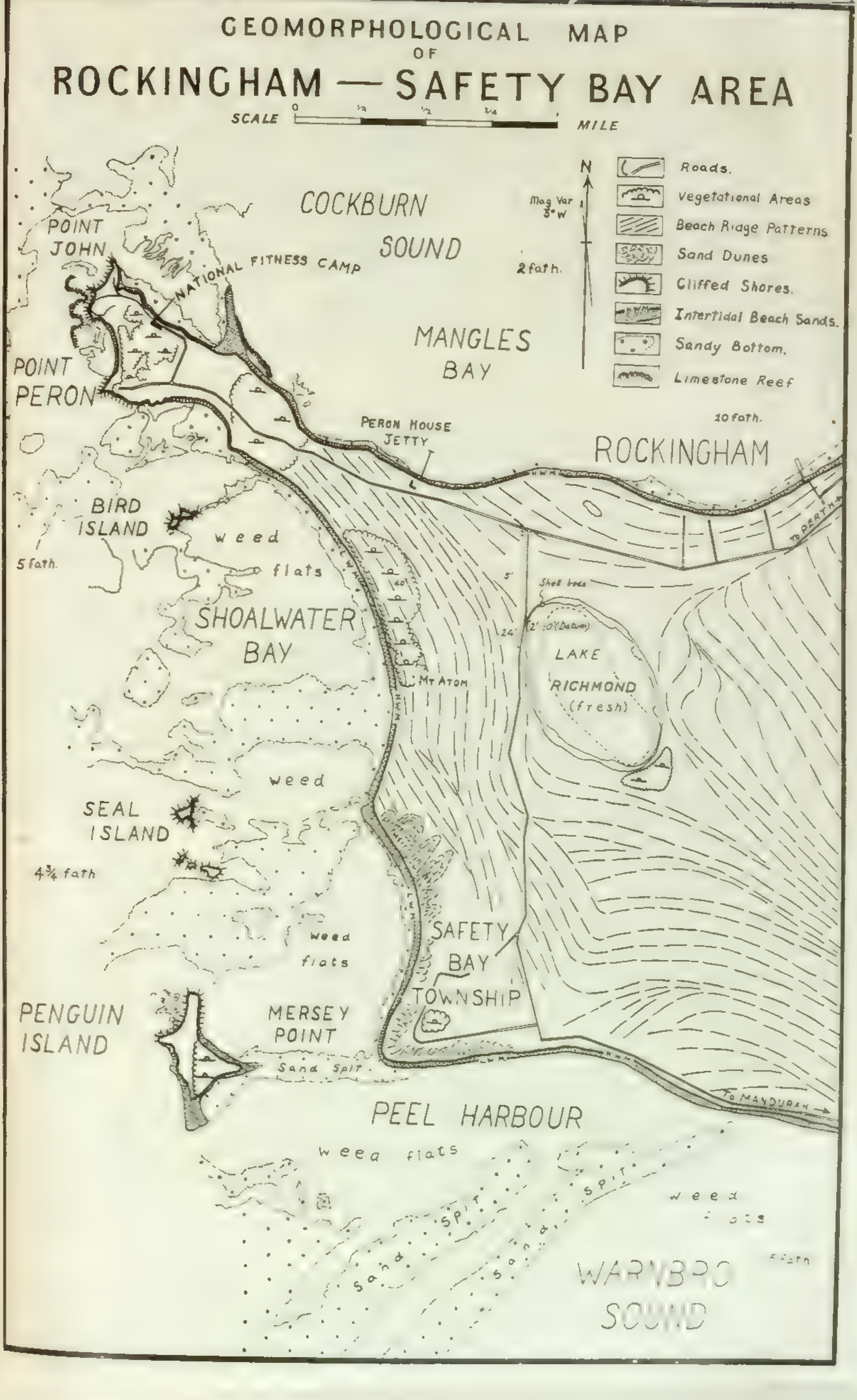
The proximity of this picturesque headland to the populated centres of Perth and suburbs with their educational establishments makes it particularly desirable that a fairly detailed description of the spot should be made ; for Point Peron appears to hold in microcosm a fair proportion of the geological and geomorphological features of the coastal belt of Western Australia which extends in a remarkably uniform way for many hundreds of miles.

In November, 1946, a combined survey by the Geology and Biology Departments of the University of Western Australia was made of the area and a detailed map was prepared by means of ground traverses with the assistance of air photographs. The author has subsequently visited the spot on numerous occasions with student excursions, and a special excursion for the Perth meeting of the Australian and New Zealand Association for the Advancement of Science was made here in 1947.

The present study will be restricted mainly to a description of the broad geological and geomorphological features. It must be emphasised that there is still an abundant scope for comparative palaeontological and sedimentary petrographic investigations. Hitherto nothing has been published on the various aspects of reef ecology, either plant or animal, and even the essential description of living species is still very incomplete.

Point Peron represents an isolated rocky headland in the nature of a tombolo—a former rocky island now "tied" to the mainland by a series of low sand-banks and beach-ridges (*see* text fig. 1 and Plate I.). As noted in the Admiralty "Pilot" (vol. V., p. 327) it may give the impression of being a true island when seen from a distance. The headland is 950 yards long from North to South and about 400 yards across from East to West. It is "tied" to the mainland in the South-East and is exposed to the open sea in the South and West and to the rather protected waters of Cockburn Sound to the North-East (Mangle's Bay). The northern extremity is known as Point John, a tiny promontory in the North-West is called Fisherman's Head, while the main feature of Point Peron projects to the South-West with a large isolated "stack" 50 yards long lying in front of it. The broad sweep of sand to the North of Point Peron we call Long Reach, and a small bay of particular interest about 300 yards South-West of Point Peron our biologists have called Haliotis Bay. From here to the South-West there is a broad sandy sweep which represents the northern end of Shoalwater Bay, which runs down as far as Safety Bay.

The rocky headland at Point Peron is only one of a series of rocky ridges, or islands, and reefs which parallel the coast in a North-South line from just East of Rottnest Island through Carnac Island, Garden Island, Point Peron, Bird Island, Seal Island, Penguin Island and the Murray Reefs—a distance of over 30 nautical miles.



Text fig. 1.

[illegible]ical map of Rocking[illegible]/Safety Bay area. This map is based on the interpretation [illegible] and personal re[illegible]ssance. Note how the rocky headland of Point Peron is "tied" [illegible] to the [illegible] and how Penguin Island, Bird Island, etc., are nearly connected to [illegible]. The beach ridges of the Coastal Plain partly parallel the shore and [illegible] le. Major changes in the coastline about Peel Harbour [illegible].

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A range of similar hills is also encountered forming the coastline North and South of Fremantle and extending South of Woodman Point, where, forming the eastern shore of Cockburn Sound, it continues southwards as far as Mandurah and beyond. This coastal range is parallel to the off-shore line of islands and reefs which lies about five miles to the West. Between Point Peron and the inner rows of hills, however, a broad sandplain has been built up and this extends as far South as Safety Bay, whereupon the shore swings back once more to the East. In this manner Cockburn Sound to the North is separated from Warnbro Sound to the South. At the southern end of Cockburn Sound is situated the large seaside town of Rockingham, while at the northern end of Warnbro Sound there is the growing seaside resort of Safety Bay.

Point Peron, with its narrow neck of sand, thus forms the north-western limit of this sandplain, while to the South-West, Penguin Island is only separated from the sandplain (at Safety Bay) by a very shallow sand spit. In between Point Peron and Penguin Island, Bird Island and Seal Island are also only separated from the shore by rather shallow sand spits. There is thus a high degree of symmetry about the area, the explanation for which we shall discuss below (Sec. III, (e)).

A short note on the tidal characteristics is essential in the study of coastal physiography, and we are fortunate at Point Peron in having an official recording station situated not far off at Fremantle (*see* recent work by A. Bennett, 1939). Mean sea-level there was determined in 1933 at 2.27 feet above datum (fixed by harmonic analysis at lowest low springs) ; the annual range of mean sea-level, however, was found to be 2.26 feet. The neap range is about one foot and the mean spring range about three feet. Thus the mean spring high tide is 3.8 feet and the mean spring low is 0.8 feet. However, with the annual swing of mean sea-level, we get an overall mean spring range of something over five feet.

On the other hand, as pointed out by Curlewis (1916), the small tidal range, the width of the continental shelf and the open nature of the coast involves a high degree of interference in the tidal characteristics by prevailing wind and meteorological elements. In this way a land wind blowing for several days will result in exceptional and almost unchanging " low " tides, while steady westerly to southerly gales will result in days of exceptional and steady high tides, although a diurnal rise and fall is often identifiable but superimposed on the general banking up of the water. In this way the overall, *i.e.*, annual, range of about five feet is even further increased and swash may cause additional banking on an exposed headland like Point Peron to produce the physiographic effects of a tidal range of more like six feet. By kindness of Mr. L. A. Jones of the Harbours and Rivers Department (P.W.D.), I was informed that owing to this "banking effect," the highest recorded tide at Fremantle was 6.25 feet (in 1910) and the lowest was minus 0.5 feet (in 1896). The physiographic effect of such rare abnormalities, however, appears to be negligible.

As regards general weather conditions, the southerly or south-westerly wind directions may be regarded as prevailing, but in the summer months the easterly element is often experienced during the early part of the day, accentuated by the normal land breeze, while the sea breeze generally comes in during the afternoon and blows with considerable force for a few hours.

For the examination of reefs the lowest tides are desirable, and a combination of these with easterly winds is often experienced about the times of the equinox and in the early mornings in October and March.

The rainfall at Point Peron is somewhat variable, but generally falls between April and October, and ranges from 30 to 40 inches per annum.

The vegetation on the sand-dune and coastal limestone country is very uniform all along the temperate coastal belt of Western Australia. Mr. G. G. Smith, of the Botany Department of the University of Western Australia has been kind enough to identify the following flora from Point Peron :—

Mesembryanthemum aequilaterale Harv.
Olearia axillaris (D.C.) F. Muell.
Frankenia tetrapetala Labill.
Suaeda australis (R. Br.) Moq.
Lepidosperma gladiatum Labill.
Clematis pubescens Hueg.
Scaevola crassifolia Labill.
Acanthocarpus Preissii Lehm.
Scirpus nodosus Rottb.
Spyridium globulosum (Labill.) Benth.
Tetragonia expansa Murr.

The only common native species of land-shell found at Point Peron is *Bothriembrium bulla* Menke, 1843 ; curiously enough it is only found sub-fossil, and bleached white, in a light brown soil, which has formed over some of the older, vegetated sand-dunes. It is found living at Rockingham and on the Swan River, in damper localities, which suggests a very recent deterioration of climate at Point Peron. A much less frequent land-snail in this fossil soil is the delicate *Austrosuccinea contenta* Iredale (— *Succinea oblonga* Menke). The only living snails here today are *Cepaea pisana* and *Cepaea acuta*, both European introduced forms (personal communication : Mr. L. Glauert).

Below high tide level a wealth of marine flora is encountered. Since this vegetation almost certainly plays an important part in the physiographic development of the reef itself, as will be seen in the discussions below, it is worth while listing the principal representatives. Again, we are indebted to Mr. G. G. Smith for his assistance.

(i) Algae forming a green mat in the ramp-notch-splash zone :
Ulva lactuca Ag.
Entromorpha compressa Link.
Chaetomorpha area (Dillw.) Kuetz.

(ii) Algae of the basal carpet on the reef flat :
Ceramium clavulatum Ag.
Jania fastigiata Harv.
Polysiphonia sp.
Hypnea musciformis (Wulf.) Lamour.
Lithothamnion sp.
Caulerpa cylindracea Sond.

(iii) Large algae anchored in basal carpet :
Sargassum spp.
Cystophyllum muricatum (Turn.) J.Ag.
Ecklonia radiata (Turn.) J.Ag.
Pterocladia capillacea (Gmel.) Born. and Thur.

There are numerous other green, brown and red algae contributing to the flora of this carpet and also down in the undercut off the reef margin and in the deeper habitats offshore.

An analysis of the shelly marine fauna will be found in Appendix I. and II.

II.—GEOLOGICAL BACKGROUND.

(a) General.

The oldest rock of the headland consists of a calcareous dune rock locally known as the Coastal Limestone formation and taken to be late Pleistocene in age. In many places in Western Australia, intercalated in the dune rock (or "eolianite") at about present sea-level, there are isolated lenticles of beach and shallow marine deposits, which presumably indicate a temporary submergence during the otherwise mainly eolian sedimentation; no example, however, has been recognised in the Point Peron area as yet. The Coastal Limestone is also intercalated by horizons of travertine and fossil soils which likewise appear to represent temporary interruptions in the eolian accumulation. Well-marked fossil soils have been recognised both on Point Peron and on Penguin Island.

The whole Coastal Limestone Formation is comprehensively affected by solution phenomena resulting in further travertine crusts, solution pipes, root structures and other characteristics. The bulk of these karst features may be seen at various points to disappear beneath sea-level and are therefore to be regarded as pre-dating the present erosion cycle. On the shore the Coastal Limestone forms high cliffs in many places and broad reef platforms extend seaward.

Overlying the old consolidated dune rocks of the Coastal Limestone there are series of loose Recent dunes which rise to a height of 88 feet. In places incipient travertinization may be recognised in these Recent dunes.

Around the beaches there are fair-sized deposits of contemporary beach sands and in the beach-ridges of the broad sandy plain, which connects the headland of Peron with the hills five miles to the East, there are very extensive accumulations of earlier Recent beach sands, the height of which has been partly augmented by wind action.

The Coastal Limestone is the main rock type which forms the two parallel ridges described in the Introduction, the outer one through Garden Island and Point Peron being rather dissected and partly inundated, so that it is only represented by reefs today; and the inner one forming the first range of coastal hills some five miles to the East.

Relatively little is known of the basement which underlies the Coastal Limestone of the Western Australian coastal plain hereabouts, but a deep artesian bore put down by the Army authorities at Point Peron in 1944 (Bore No. E16) reached 1,412 feet and provided an artesian flow of water measured at 14,000 gallons per hour. The water is fairly hot (just over 100°F.) and is rather sulphurous, with a high percentage of dissolved salts. The percussion bore used naturally gives a rather poor indication of the strata penetrated, but the broad features recorded by the driller indicate shaley sands (with marine bands) to 120 feet, below which are sands and sandy limestone to 200 feet; all of which sounds like the lower parts of our Coastal Lime-

stone. From 200 to 700 feet is a calcareous limestone with marine shells of unknown age ; from 700 to 900 feet there are black pyritic shales with sandstone and glauconite bands. I have been fortunate enough to see some specimens of these, and the bright green glauconite bands may possibly be compared with the Upper Cretaceous glauconites of Gingin and Dandaragan. The black pyritic shales are also of a type found associated commonly with Cretaceous rocks in the artesian bores of Perth. From 824 to 1,230 feet there are pyritic black shales alternating with fine grey sandy shales which contain foraminifera between 824 and 930 feet and may also be compared with the Cretaceous (possibly Lower Cretaceous) below Perth. At 1,230 feet there is a conglomeratic grit horizon passing down into loose sand and sandstone to 1,412 feet, carrying water. This again, we may compare with the so-called " Claremont " water horizon below Perth, which may be of Upper Jurassic age.

(b) Coastal Limestone.

(i) *Eolianites.*—The Coastal Limestone of Western Australia has been known for more than a century and a half; its discovery dates back to before the foundation of the Colony, having been observed in the vicinity of King George's Sound by Vancouver on his voyage around the world in 1791. It was described in more detail by Peron and Freycinet (1807–16, pp. 75, 168–73). While Vancouver and others had taken the rock to be mainly of coral origin, Peron and Freycinet recognised it in all its essential features, *i.e.*, as a subaerial deposit originally consisting of wind-blown beach sands and containing shell debris from the beach together with terrestrial snails, bones and vegetable remains. The term " eolianite " was only relatively recently applied to this type of rock by Sayles in his work on Bermuda (1931) ; in America and Australia the older spelling of " æolian " is now often discarded.

It is not necessary here to go into a long report on the history of this formation, as it has recently been summarised by Teichert (1947, pp. 182–185). We may merely confirm his conclusions and emphasise that all the evidence points to the formation of this wind-blown rock during one or more of the Pleistocene glacial periods when the low eustatic sea-level exposed broad areas of continental shelf sands to eolian erosion.

Similar rocks are now recognised around practically all of the more gentle sloping coast lines of the world in warm-temperate and arid latitudes. The rock itself consists of rounded grains of quartz and other resistant minerals with a varying percentage of calcium carbonate consisting of fragmental remains of mollusca, echinoidea, foraminifera, bryozoa, calcareous algae and smaller quantities of coral and other calcareous invertebrates.

The proportion of calcareous to insoluble minerals varies very greatly from place to place, but a characteristic sample collected by Miles from just South-West of Point John showed 80 per cent of soluble carbonates (Miles, 1945). The whole mass is more or less cemented together by carbonate material which has been dissolved out of the higher layers by rainwater and reprecipitated lower down in the old dunes. Very great local variations are thus encountered in the degree of hardening and in the amount of calcareous enrichment.

It is generally considered that the superficial layers of the old sand dunes which had lost the bulk of their calcium carbonate under this leaching process, were reduced already in Pleistocene times to the character of loose

siliceous sands which were then blown away once more to be deposited further inland where today there are extensive plains of white siliceous sands quite devoid of calcium carbonate (Crocker, 1946).

In the cliffs at Point Peron today we observe a cross-bedding of these old dunes very nicely exposed with steep dips in places up to 32°, and in the general way dipping East or North-East, *i.e.*, away from the prevailing wind. It will be noticed how the individual stratification planes are more hardened by calcareous enrichment than the intervening accumulations (*see* text fig. 2). It has been suggested that each plane was thus hardened by a shower of rain during its accumulation, but the uniformity of the stratification through hundreds of feet forces one to reject this explanation. It seems more likely that trickling calcareous solutions penetrating the former dune from the original surface would tend to be deflected down the old planes of accumulation, and would thus provide this striking banded effect.

Text fig. 2.

Typical section of steeply bedded eolianite from an exposed position just south of Fisherman's Head where secondary [illegible] planes and vertically in the "pencil structures." Note the honeycombed weathering of the non-indurated parts. Hammer with 18 inch handle indicates scale.

A second feature of this calcareous enrichment is a network of vertical pencil-like structures varying from one quarter inch to two inches in diameter, and running vertically through the rock from top to bottom (*see* also text

fig. 2). These appear to pass straight through the diagonal hardened planes and may be due to precipitation of calcium carbonate from *vertical* trickling solutions which took place contemporareously with the oblique hardening.

Under wind and rain erosion the less resistant pockets of the old eolianite lying between the above-described features tend to be scooped out and washed or blown away. In this way a pronounced honeycomb effect is produced on the rock surface. Owing to the hardening of the surface by travertine crusts, the tops of the cliffs tend to be well preserved, while eolianite lower down, being much softer, tends to be scoured out by the forces of wind and rain, producing large cavernous structures and " natural bridges " (*see* photos by Gentilli, 1948).

Macro-fossils are hardly known in the eolianites of the Coastal Limestone, but in places large shells have been carried up by sea birds (Teichert and Serventy, 1946), and in other places aboriginal kitchen middens may be mistaken for marine deposits associated with the eolianite. In other exposed places quite large shells may be blown up a moderate distance (say 50 feet), to be incorporated in the eolianite, but this is distinctly unusual and normally the only intact shells found in the eolianite are the foraminifera, which, with their light structure and air chambers, are very easily carried by wind. No comprehensive study of the foraminifera of the Coastal Limestone of Western Australia has yet been carried out, but as far as has been recognised they appear to be mainly living species, but not always of local occurrence today (*see* Appendix II).

(ii) *Soil Horizons.*—At various heights around Point Peron and on Penguin Island in the old eolianite formation, there are layers of very hard travertine varying in thickness between three and 12 inches. The upper surface of these layers is rather smooth and the lower side merges indistinctly into the underlying eolianite. Such travertine horizons have the appearance of being relics of former " hard pans," which normally form at a few feet beneath the surface of the ordinary ground level.

Resting on the travertine surface is a thin or sporadic layer of reddish to chocolate to greyish-brown sandy soil which has the character of some of the more sandy " terra rossa " residual soils of the Mediterranean, in particular those forming on the coastal belt of Palestine. This soil horizon is found to pass downwards to partially fill some of the former solution pipes which are initiated in the travertine horizon and penetrate the underlying eolianite. In this way certain of the solution pipes are almost or completely filled by alternating layers of this reddish soil and coats of travertine. The soil, on analysis, was found to be a calcareous sand with traces of phosphate : $CaCO_3$ 16 per cent, clay 2.5 per cent ; sand 78 per cent (including small amounts of heavy minerals) ; organic matter, etc., up to three per cent. In one sample there was six per cent Fe_2O_3.

In many places in the soil, particularly next to the walls of the solution pipes, are small sac-like or egg-shaped fossils from one to two inches in length, preserved in travertine. These have been compared at times with turtle eggs, wasp nests, etc., but Mr. L. Glauert of the Western Australian Museum, has kindly drawn my attention to a paper by A. M. Lea (1925) referring to them as calcareous insect puparia, the majority of recently formed specimens found in South Australia being correlated with the large weevil (*Leptops duponti* Boisd.). No doubt other large insect larvae form similar cocoons, but since all our Western Australian examples are only in fossil form, no soft parts remain to indicate the precise form of their original inhabitants.

Overlying this obviously fossilized soil horizon follows a higher sequence of cross-bedded eolianites. Soil horizons of this type are found very well developed in the eolianites on the islands of Bermuda (for example, *see* Sayles, 1931), Bahamas, and elsewhere, as well as elsewhere on the coast of Western Australia, *e.g.*, at Hamelin Bay. At Hamelin Bay, however, the soil horizons are more numerous and thicker than at Point Peron, and it appears possible that during the arid low sea-level phases of the Pleistocene the frequency and development of such soil horizons decreased from South to North.

Land snails, such as *Bothriembryon*, are generally associated with these fossil soils, but none were found in it at Point Peron, except in the youngest soil, formed on the vegetated dunes. These youngest soils are clearly older than the freshly-formed, moving dune sands of today and, judging by the thickness of soil (one to three feet), may have been in existence many centuries. Incipient travertinization is to be seen in them in the form of some weak " root structures," but no hard pan has developed yet. As noted above, bleached shells of *Bothriembryon bulla* Menke, are found in this soil, but are not found living on the surface today. Rare specimens of *Austrosuccinea contenta* Iredale are also encountered in it.

(iii) *Karst Features.*—As indicated above, the entire Coastal Limestone Formation, including both eolian and marine members, was subjected, during what was probably the last glacial period of low sea-level, to intense subaerial erosion. In the course of this attack by rainwater, the calcareous eolianite reacted in very much the same way as a pure limestone, such as is so well known in the classic localities of the karst country of Europe. Running water trickling through the porous sands produced impoverishment of calcium carbonate in the upper layers and produced enrichment below, with hardening along the bedding planes and along vertical pencil-like structures (*see* text fig. 2).

These vertical solutions, however, went further, and open pipes were dissolved out, some of these " sink holes " ranging up to 10 feet and more in diameter, but the bulk averaging only one to two feet (*see* text fig 3 ; *see* also photos of pipes near Moore River, Fairbridge, 1947). In places these pipes are found in great profusion, there being almost more pipe hollows than solid rock, while in others there are practically no pipes at all.

A preliminary examination of the distribution of these pipes at Point Peron and elsewhere along the Western Australian coast seems to indicate that the maximum concentration of the pipes coincides with the depressions in the old dune surfaces, as indicated by the depressions in the surface travertine crusts. To begin with there was the formation of a fairly massive layer at some distance below the surface of the dune, a horizon coinciding most probably with the average height of the water table, where occurred the major redeposition of the calcium carbonate which had been dissolved out of the dune sands higher up.

We may imagine now that when this travertine crust became so thick and massive that it was no longer pervious to water like the porous dune rock, the descending solutions would be deflected laterally to flow down over the surface of the crust until they reached depressions between the dunes. As is well-known with irregular dune landscapes, such depressions are often closed basins from which there is no escape of water except downwards. With the accumulations of swampy pools of water in these basins a powerful solvent concentration would be developed, which would seek out any lines of weakness in the underlying crust, penetrating it in many places like a sieve and flowing downwards eventually to reach somewhere about sea-level.

Text fig. 2.

A solution pipe or " chimney " overlooking Point Peron, almost completely exposed by the erosion and removal of the surrounding country rock. It is almost hollow as may be seen through the broken section of the travertine wall near the top. The " hour-glass " constriction appears to be due to an obstruction caused to the downwards working solutions by a hard horizontal band of pre-existing travertine crust. Traces of small root structures may be seen on the outside of the wall.

Horizontal channels which would eventually connect many of these vertical pipes with the sea, as underground rivers, have not been identified above the present sea-level at Point Peron, but are believed to exist somewhere below our present stand. Analogous channels have been recognised in operation today in the karst-affected raised limestones of Middle Island in the Abrolhos Group (Fairbridge, 1948) and horizontal channels have been identified beneath some of the reefs at Point Peron, and these are believed to have been caused in this manner during the Late Pleistocene karst cycle.

After these pipe structures were hollowed out by moving water very reduced quantities of solutions supersaturated in calcium carbonate (possibly under conditions of reduced rainfall) trickled down the walls of the pipes and redeposited layer upon layer of travertine. These layers are often discoloured by various shades of red and orange by the contemporary dust and soil formations. The walls thus formed are generally much harder than the surrounding country rock, and now when re-exposed to subaerial erosion they stand up like chimneys (*see* photos in a recent article by Gentilli, 1948). The fact that they were formed during an earlier cycle is clearly indicated at Point Peron headland, especially at the northern end of Long Reach and on the northern side of Point Peron itself, as evidenced by the fact that pipes may be seen disappearing straight down below sea-level ; in places they may be seen to extend more than 30 feet up and down. It is also apparent that these pipes at certain times, at any rate, were in contact with the open air, because in very many places down in their walls may be found the little sac-like protuberances which have been identified as fossil insect cocoons of the same type as in the soil horizons. The exits from these cocoons are now in many cases covered by layer on layer of travertine.

Associated with the travertine bands and the solution pipes are fossil root structures (the "rhizomorphs" of Northrop in the Bahamas, 1890), which wind and twist about just like the roots of contemporary scrub, except that they are almost completely replaced by travertine. In places only the rough pseudomorph is recognisable, but in others almost cell by cell replacement of the woody material has occurred.

(c) Recent Beach-rock.

In places at Point Peron, apparently plastered on to and embedded in pockets in the already eroded Coastal Limestone shore at or about the present sea-level, there are deposits of calcareous sand consisting of broken shell debris, foraminifera and quartz grains, but of rather more angular nature than the rest of the eolianite, and in places containing complete shells as fossils. This formation in contrast to the eolianite is generally found dipping seawards, *i.e.*, to West or South-West, and at a gentle angle (about three to seven degrees). The bedding, furthermore, lacks the parallelism of the big dune deposits and shows fine cross-bedding in places. It also exhibits evidence of water sorting with coarse and fine bands alternating. It is completely indurated by calcium carbonate in a very uniform manner and contrasts thus very strikingly to the irregular induration of the normal eolianite. Thanks to its gentle seawards slope and uniform lithology, it tends to joint and break up into rectangular blocks. One has, therefore, little hesitation in identifying this formation as a "beach-rock." It is well exposed on the shore of Long Reach and again in Haliotis Bay.

This beach-rock, as is well known, forms by calcium carbonate precipitation in contemporary calcareous beaches around all warm-temperate and tropical shores today (*see*, for example, Fairbridge and Teichert, 1948). The process is not yet thoroughly understood, but the formation of the rock appears to be due to the percolation of lime-rich solutions carried down through the porous upper parts of the beach by rainwater and reprecipitated in the inter-tidal zone where the acid rainwater becomes neutralized by alkaline sea-water. The factor of heating under the sun's rays when the beach is exposed at low tide, would also assist such precipitation (there is a bulky literature describing these effects and processes which we need not refer to further at this juncture). Contemporary beach-rock is exposed from time to time by changes in the overlying beach sands at certain seasons.

(d) Contemporary Beach-sands, Muds, etc.

Small to moderate amounts of beach-sands are accumulating today along the broad sweep of Long Reach, Shoalwater Bay and Mangle's Bay and a small amount in Haliotis Bay. This beach material averages about 90 per cent calcium carbonate in the form of broken fragments of all types of molluscan shells, echiniodea, bryozoa, froaminifera, corals (which are unimportant) and of calcareous algae of the *Lithothamnium* type.

The bulk of this material is broken down into rather flat flaky fragments averaging half to one millimetre diameter. The material is rather angular with little rounding. Of the insoluble fraction the most important mineral is quartz, and this is in the form of extremely well-rounded grains. Only one to two per cent of the whole consists of the resistant heavy fractions. It appears that the insoluble members are of re-worked origin, while the calcareous material is derived from recently fragmented organic sources.

An additional sediment found on the protected North-East shore, *i.e.*, facing Mangle's Bay, is a whitish mud which is extremely fine-grained and appears to be an inorganic precipitate of calcium carbonate of the type commonly recognised in certain coral reef lagoons, *e.g.*, Houtman's Abrolhos (Fairbridge, 1948), and in similar regions where calcareous eolianite is being eroded, such as the Bahama Banks and the Florida Keys.

(e) Recent Dune and Beach-ridge Sands.

During periods of neap tides, especially during the long dry summer season, the beach sands accumulated under the influence of storms and high tides tend to be dried out and are blown up into coastal dunes, which at Point Peron headland reach a height of 88 feet. These dunes are mainly vegetated today by dune grasses and scrub, which suggests possibly wetter climatic conditions in most recent times. The sand material in these dunes is much the same as that of the beach but quickly becomes reduced in size and much more rounded. I have seen quite heavy shells up to three inches in diameter rolled up the beach to a height of 50 feet in these dunes, but they never seem to reach far inland. Other shell deposits are attributable to the agency of bird and man (*see* Teichert and Serventy, 1947), but in the general way the only intact shells found in these dunes are the very small mollusca and foraminifera.

Parallel to the broad sweep of the shallow, gently shelving shores of Shoalwater Bay, etc., we find numerous parallel rows of beach-ridges. Like the sand-dunes, these too are well vegetated today. Such beach ridges are usually quite quickly overgrown where they have been thrown up above the normal limits of waves, and blown sand caught in this vegetation tends to build them up higher still, so that, strictly speaking, most of the sand beach-ridges have an element of dune ridge about them. The material of these beach-ridges is analogous to that of the present beaches and their adjacent dunes, but all analyses to date indicate a rather low percentage of calcium carbonate near the surface. It would appear that considerable downward leaching had taken place over the last few centuries.

At no point in the region of the Peron headland was I able to demonstrate the formation of a contemporary beach-ridge, or even one formed during the historial period. The height of the beach-ridges and their geomorphological features suggest, in any case, that these formations pre-date the contemporary cycle at the present stand of the sea-level (*see* further, Sect. III, e). It will be seen that the main group of ridges rise from a sand plain averaging somewhat over 10 feet in elevation.

At Point Peron, immediately South of the point itself, a most interesting section is visible, illustrating the relationship of these early-Recent beach-ridge sands to the 10-foot bench of the coast. First a hard beach-rock plaster, full of shells, is found grading up from the 10-foot bench to about 15 feet above datum, and from here up to 24 feet is a typical " raised beach " of loose shell sands. The shells include many gastropoda, but also pelecypoda, echinoderm spines, foraminifera, fragmentary bryozoa, cirripedes, chitons, serpulae, spirulae, etc. The assemblage differs in some respects from that of the present beach (*see* Appendices I and II.)

Other shell beds may be seen in various cuttings and sand pits, mostly between 10 and 20 feet above datum, between Rockingham and Safety Bay. None, however, have been found to be nearly so prolific as that at Point Peron itself. A more interesting section is exposed along the shore of Lake Richmond at about six feet above present datum (and thus well below the low tide level of the 10-foot sea). Here, somewhat crusted by lake travertine, is a somewhat similar assemblage but possessing in addition pelecypoda such as *Katelysia scalarina* (Lamarck), with both valves in place, suggesting undisturbed sedimentation in a protected spot. Geomorphological observations indicate a possible explanation (*see* again Sect. III, e), that this area was formerly a bay open to the North, but cut off to the South and West by successive beach-ridges.

III.—GEOMORPHOLOGICAL FEATURES.

The general geomorphological aspect of the Point Peron headland and vicinity was indicated briefly in the introduction. It is a rocky headland of Pleistocene eolianite, " tied " in the form of a tombolo by a large number of successive beach-ridges to the adjacent mainland, the rocky parts of which lie five miles to the East across a flat plain ridged only by these parallel rows of ancient beaches. Of this feature I will have more to say below.

Around the cliffs of the rocky headland of Peron, Garden Island, Penguin Island, etc., there are a number of interesting erosional features both belonging to the contemporary marine cycle and to previous periods when somewhat higher sea-levels existed. I shall describe first those of the present cycle :—

(a) Contemporary Marine Platforms.

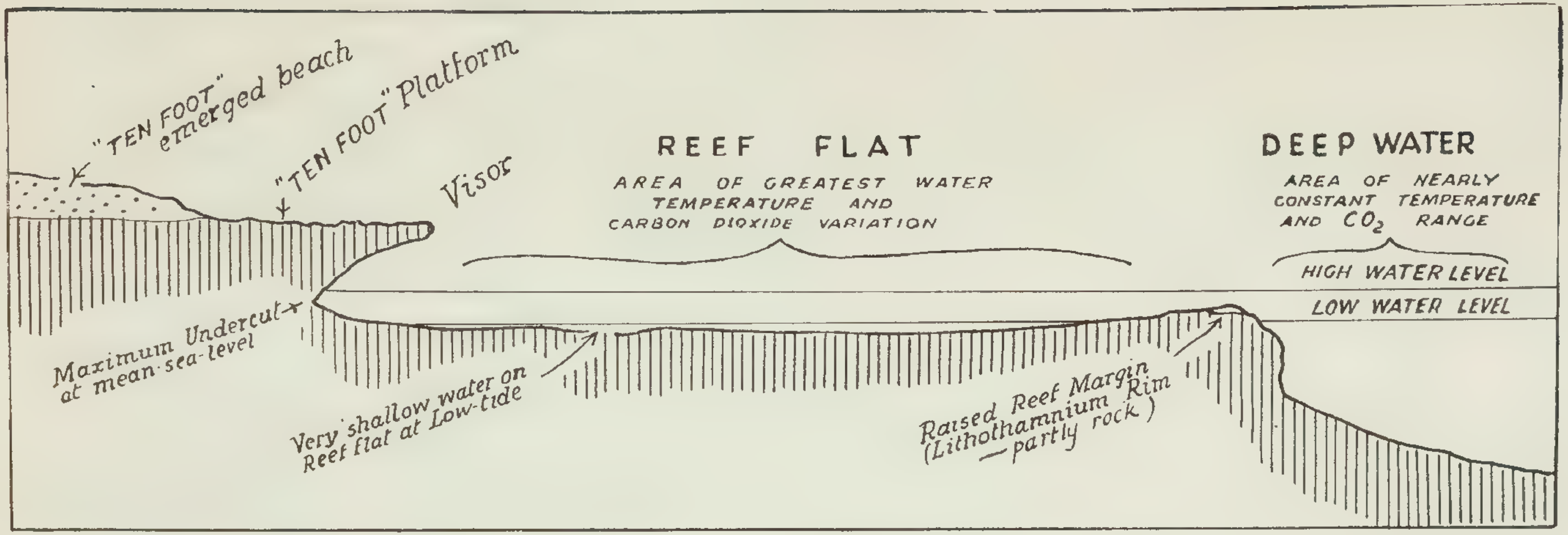
The present marine cycle is observed to be in the process of cutting out a series of broad marine platforms otherwise known as " water-level benches," or, quite simply, " reefs." The expression " reefs," however, should not be taken to imply that these features are coral reefs. The occurrence of corals in this region is quite a rarity, and they are better described as " limestone reefs," though sometimes, but less accurately, named "sandstone reefs."

(i) *General.*—These contemporary marine platforms extend out to sea for a distance of up to 200 yards where the main force of the waves is spent. Their outer edges follow an almost North-South line from West of Point John for over 1,000 yards to somewhat South-West of Point Peron itself. However, all is not one massive reef but there are many " bays " and indentations in the reef flats where quite deep water comes close in to the shore. Isolated " stacks " and small islets rise off-shore from the surface of the platform. The general level of the platform is about the height of datum (low water springs), but in certain areas the surface is irregular and several feet below datum, while on the outside edges there is generally a somewhat raised rim. Nevertheless, the average height of the reef is within a few inches of datum.

The reason for this planation of the limestone to form a horizontal bench or reef at about the level of low water spring tides has never been explained on the West Australian coast. I indicated something of the nature of the process in a paper on the Abrolhos (Fairbridge, 1948) and the subject is still under research. Briefly the problem is this : as Macfadyen (1930) in the Red Sea, Kuenen (1933) in the East Indies, and several other authors quite recently have pointed out, limestone coasts, particularly in the warmer waters of the world, are undeniably being subject to chemical solution by the surface layer of sea-water. Normally speaking, sea-water is supersaturated in calcium carbonate and cannot dissolve further quantities. There is no evidence of solution going on at depth as has been postulated by Murray to account for coral reef lagoons.

In a thin layer, restricted to the surface of the sea near the shore, sea-water is believed to act as a powerful solvent which attacks and undercuts limestone cliffs and reduces them to horizontal reef platforms, at a level which corresponds both to the lowest limit of subaerial erosion and also to the lower limit of this superficial marine solution, *i.e.*, the level of low spring tides (*see* text fig. 4, page 49). It is observed that mechanical and biological forces assist the chemical, but that the latter is the controlling influence. It is suggested that, with a sharp rise in temperature and loss of CO_2 (both raising the pH) in the shallow water (especially just on the surface) on the reef flat on a hot sunny day, there will be a precipitation of calcium carbonate from the supersaturated sea-water. In the night there will be a considerable drop in temperature in the shallow water of the reef flat, reducing the pH and making the water relatively " acid." In addition at night, the photosynthesis (with absorption of CO_2) by reef plants will be interrupted, and additional quantities of CO_2 will be liberated by animals and plants, further reducing the pH. The role of surf in taking excessive quantities of CO_2 into solution may also be considered.

The deeply etched and jagged surface of the limestone at the undercut cliff edge is plain for all to see. In striking contrast are the smooth, polished surfaces occasionally found where mechanical abrasion (by sand) has been operative. Biological action, by boring worms, pelecypoda, echinoids, algae



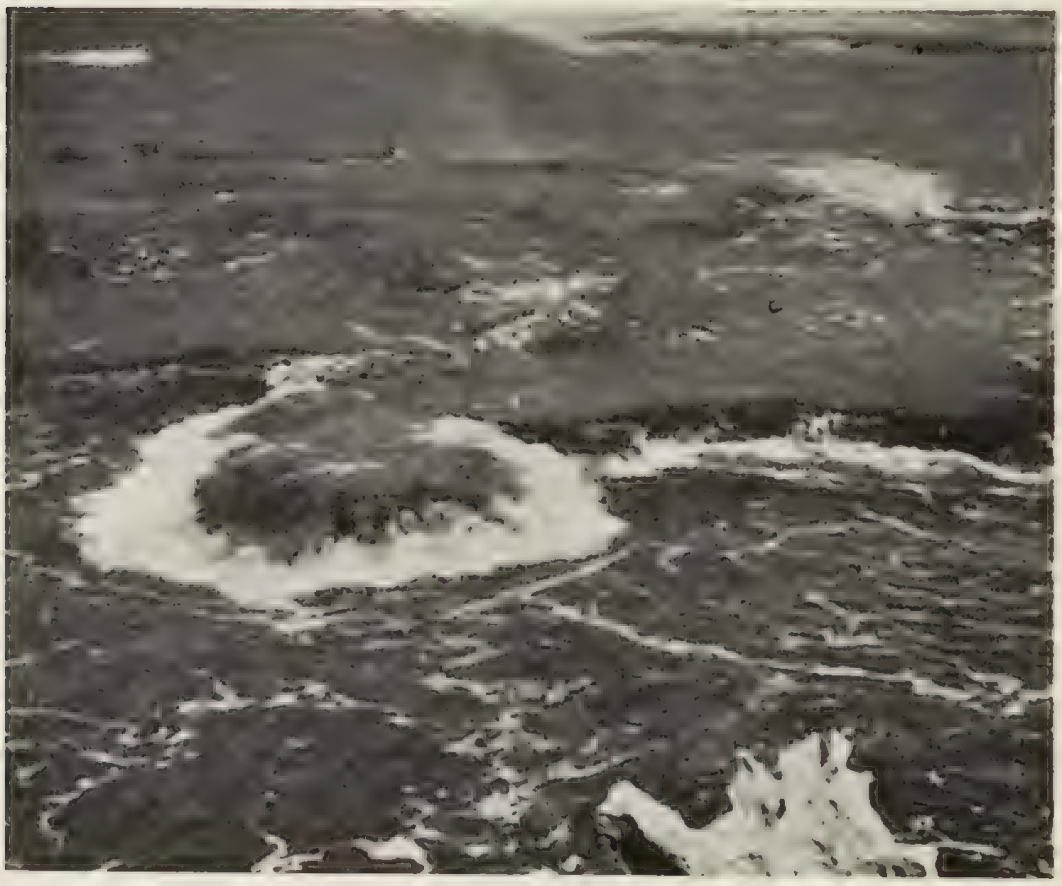
Text fig. 4.

Section across an idealized reef-flat cut in limestone rocks. It will be seen how the bulk of the reef is reduced to the level of low water spring tides, or a little below. It is here on the reef flat and especially in the undercut notch that maximum solution effects are experienced. These features are normally protected from powerful wave action by the reef rim. The latter is generally somewhat higher than the rest, being exposed to the continual splash of waters of even temperature, and, in addition, is often further protected by incrustations of *Lithothamnion*. It is remarkable how resistant this outer rim is to mechanical erosion.

and so on, is also recognised as assisting the destruction of the reef. Nevertheless, on the one hand, the zone of maximum erosion, in the undercut and swash area, is marked by a minimum of biological agents, while on the other, the area of maximum biological attack, from the level of the low-water springs downwards, is precisely that part of the rocky coast which is best preserved.

(ii) *Raised Rims.*—The outer edge of the contemporary reef flat, whether or not it is exposed to a moderate amount of wave action and splash, is almost always raised somewhat higher than the rest of the platform : the height of this rim is generally between six and 18 inches, according to exposure. Paradoxically enough, the greater the exposure, the greater the height. The rim is generally found to be coated with incrustations of calcareous algae and is analogous on a small scale to the well-known *Lithothamnion* rim of Charles Darwin, found on the great coral reefs of the Pacific and Indian Oceans.

In some of the most exposed outer parts of the reef the *Lithothamnion* rim is ranged somewhat in the form of steps with intermediate rims between each step, the highest terrace being to the exterior. Being surrounded with a low rim of growing calcareous algae, each of these terraces is perpetually covered by a shallow pool of water no matter what its height (up to 18 inches) above low tide line, since here on the outer edge wave splash keeps it filled with water and thus keeps the rim-building algae alive. The over-flow towards the interior fills successively lower and lower terraces.



Text fig. 5.

The low reef rim off Fisherman's Head, seen at low tide when the upsurge is spilling water over the rim onto the reef flat. The horseshoe opening is a former " blow-hole " now broken through on one side.

Text fig. 6.

The same reef rim, seen a few minutes later, when the back-surge is allowing the water thrown onto the reef flat to drain back into the sea. Note the reversed role of the rim in holding the water up on the reef.

The inner reefs, where wave action is much reduced, are bounded simply by a single rim about six inches in height (*see* text figs. 5 and 6). At low tide in calm weather the water is thus seen to surge up over the edge of the rim, but being prevented from flowing directly back, flows sideways to escape into one of the deep channels which cut the reef. On the sides of these channels, where there is practically no surge at low tide in calm weather, the rims are very reduced or even absent and consequently allow this escape. There is thus an almost perpetual current crossing the reefs from the outside and swinging away laterally near the shore.

It has sometimes been thought that the *Lithothamnion* rim had grown up from the outer edge of a horizontal reef platform, but when this rim is broken into with sledge-hammer and crowbar it is generally found that the *Lithothamnion* only forms a thin coating or incrustation over the surface and that the interior of the rim is calcareous eolianite like the rest of the reef. Only in exceptional places is the *Lithothamnion* incrustation more than a few inches thick. This observation appears to demonstrate that the reef platform has in fact been eroded (by solution) downward below the rim level, the latter being preserved from chemical erosion in the zone of wave splash.

In certain places, particularly at the reef edge facing the transverse channels where there are very reduced amounts of wave splash and where the water current is generally flowing out from the reef back into deep water,

there are traces of a very small rim which is purely of the country rock material with no *Lithothamnion* at all. These rock rims are broken in many places, but they are nevertheless very interesting because they are raised and sharp, projecting from the steep reef edge out over deep water. They clearly demonstrate with their lack of rounding that it is chemical erosion which is going on in the interior, for in such exposed positions sharp pinnacles of this sort would soon be rounded off. The rock rims of this character are generally not more than about three inches in height.

A third, but very unusual type of rim, is encountered on the protected North-East side of the Point Peron peninsula. Here, in Mangle's Bay there is a considerable amount of white, sandy and marly calcareous sediment extending over and out beyond the reef, so that there is very shallow water for a considerable distance off-shore. Rising, however, in a few places near the shore to a height of nearly two feet above datum, are a number of micro-atolls, ranging up to three or four feet in diameter, each with a miniature lagoon in the middle (*see* text fig. 7).

Text fig. 7.
A micro-atoll coated with Mytilus, nearly four feet in diameter, found on the shore of Mangles Bay just north of the National Fitness Camp.

The rims of these micro-atolls are coated with dense clusters of a mytilid, *Brachyodontes erosus* (Lamarck), a common mussel which is found widespread in the shallow waters of Cockburn Sound. These micro-atolls are much the same type as those described on the Bermuda Reefs by Agassiz (1895), though the incrusting animal in Bermuda, according to Agassiz, was more commonly *Serpula*; still *Mytilus* micro-atolls are also known there. These Bermuda micro-atolls, like those of Point Peron, are built of calcareous eolianite with rock rims merely coated, or incrusted, with a protection of *Mytilus* or *Serpula*. The interior, or miniature lagoon, has, in both cases, been reduced below the rim level by erosion, presumably both chemical and

physical. Since, however, their protected position in Mangle's Bay prohibits any excavation by scouring due to violent wave attack, it seems most likely that it is chemical erosion which is the most important feature in the etching out of these shallow lagoons.

(iii) *Blowholes and Under-Reef Channels.*—At various points on the reef at Point Peron, but most easily observed at Fisherman's Head, there are vertical pipes or holes in the reef which, in some cases, are directly connected to the sea either in the under-cut outer margin of the reef or by means of a longer under-reef channel. In this way the breaking wave near the reef margin is followed a few seconds later by an up-surge in the blowhole and the water spills out over the reef flat. With the back-surge the water runs back into the hole.

Since the level of water is thus repeatedly raised and splashed around the rim of the blowhole, there is generally an active growth of *Lithothamnion* over the raised rim just as there is on the outer edge of the reef (*see* text figs. 5 and 6). In ordinary weather the hydraulic thrust is not enough to shoot water high into the air, but in times of exceptional storms at low tide, a miniature geyser effect is sometimes produced.

The under-reef channels, referred to above, actually connect the two sides of the narrow headland called Fisherman's Head, and a few seconds after a wave breaks on the South-West side there is a considerable up-surge of water on the North side of the Head. There appears to be a tunnel about 25 long which must be of considerable diameter, since the amount of yards water displaced in this way is quite impressive.

On the low cliffs, 150 to 200 yards South of Fisherman's Head one may observe vertical solution pipes which have been produced during an earlier cycle of karst erosion going straight down from the top of the cliffs to below sea-level. Some of these pipes, too, are in direct connection with the sea somewhere below and the water naturally surges up and down with the prevailing swell.

From our knowledge of similar karst developments with solution pipes and horizontal channels observed elsewhere above sea-level, it seems very likely that a well-developed network of former underground rivers and solution channels is connected to many of our vertical pipes. Some of these are still sufficiently free from blockage by sediment that they are open to the sea beyond the reef edge, where the water is about 10 feet deep on the average.

We thus have a system of " drowned " karst caves and channels beneath Point Peron. A somewhat similar case of " drowned " karst development of probably similar age has been described from the Abrolhos Islands (Fairbridge, 1948).

(iv) *Submarine Under-cut.*—The outer edge of the reef is what sailors call " steep-to " and the bottom drops immediately to 10 feet or more where it forms apparently a lower platform of an average depth of about three fathoms, beyond which it drops again to about five fathoms. Insufficient amounts of sounding data are available for this region to make perfectly sure of these relationships, but the present material appears to indicate that, just as there are a number of horizontal platforms on the land, there are also a number of submerged off-shore platforms.

It is perfectly clear, however, that the outer edge of the reef flat is overhanging with a visor-like projection of the reef rock. Beneath this overhang, except in places where obviously it has recently been broken off, there is almost always a deep " under-cut " which may extend back for distances between three and 15 feet.

It was noticed immediately that this under-cut is analogous in appearance to the intertidal under-cut, which we recognised at the inner edge of the present reef flat and which separates the latter from the higher reef platforms, *e.g.*, the 10-foot bench. It would not require a great stretch of fancy, therefore, to imagine the present contemporary bench inundated to a depth of 10 feet, in which case our 10-foot platform would be the new water-level reef and off-shore there would be a deep under-cut.

We might, therefore, without further ado explain the submarine under-cut at Point Peron as a phenomenon caused by inter-tidal erosion during a former lower sea-level, the height of which would have been between about 10 and 20 feet below the present sea-level. This phenomenon of the under-cut reef margin is not restricted to Point Peron. It is not by any means a local feature, and I have recognised it in many places in Western Australia and I am informed that it is commonly found elsewhere, in South Australia, etc.

There are, however, certain alternative explanations which have been presented. To begin with, we recognise the inter-tidal belt and a short distance above and below it a special zone of chemical activity in which alternate solution and redeposition of calcium carbonate is in progress. In this way, although rock material is continually being removed down to low tide level, the rock surface there is so indurated and hardened by precipitated calcium carbonate that it is extremely difficult to break, even with a sledge-hammer. Boring operations which have been carried out in search of water, etc., in the coastal limestone, generally indicate that hard crusts of this sort do not extend to any great depth and after a few feet the rock becomes quite soft again. In some places the old dune material is so unconsolidated that it simply powders in the hand. It is conceivable, therefore, that beneath a layer two to three feet thick occupied by the reef flat and its overhung rim, there is a softer horizon of old eolianite which is subject to more rapid erosion by mechanical scouring of the waves. In this way, the under-cut would be a contemporary product of mechanical wave action.

Alternatively it has been demonstrated that just below low tide line the activities of boring mollusca, worms, sponges, etc., reach their maximum intensity, and in this way the under-cut might be loosened and honeycombed by biological attack.

In answer to both these alternative proposals, however, there are a number of very serious objections. In the first place the surface of the under-cut is coated in large fleshy seaweeds and all manner of more delicate marine growths, both plant and animal. It is often plastered with pink *Lithothamnion*. Very close by I have even found specimens of the delicate coral *Cyphastrea* which could not possibly stand any great mechanical erosion. The entire surface of the under-cut is thus protected by a thick coat of living materials, and it is quite apparent that if major erosive activities were in progress bare surfaces of rock would be exposed. It is true that in places segments of the overhang have broken off and are seen to lie in the clear water at the foot of this submarine cliff. In exactly the same way large segments of the overhang between the 10-foot platform and the present bench may be seen to have broken off. This would seem to be a natural result of the tremendous hydraulic power of waves, possibly aided, to some extent, by the activities of boring animals and plants. Nevertheless, the scars left by the broken off segments are quickly covered again by a mat of living organisms, and it appears to be most improbable that a contemporary mechanical form of erosion is responsible for the under-cut itself.

As for biological attack being solely responsible, we have the evidence of particularly large blocks which we have broken off the edge of the reef by means of crowbars and sledgehammers. It was only with the greatest difficulty that these segments of the reef were obtained, and in the resultant cross sections of the reef rim it was found that boring animals only reached a depth of six to nine inches, to the interior of which was found a pure eolianite rock, the grains of which are cemented together in the most massive and resistant manner. Thus we must reject also the explanation of biological attack as the sole factor in producing this under-cut, and the conclusion reached is that the under-cut was formed during an earlier cycle of erosion under intertidal conditions when the sea-level was at least 10 feet lower than it is today.

(b) Emergent Platforms and Shell Beds.

We have seen above how there are extensive contemporary marine platforms around the promontory of Point Peron, and stepping back up the shore and cliffs of the rocky parts we find a succession of emerged platforms which exhibit many of the same features which we have recognised in the ones forming today. We recognise their horizontal indurated surfaces although in many cases they are deeply dissected ; nevertheless, in the same way that a " Gipfelflur " in mountain geomorphology enables us to recognise a former peneplain, the conformity of heights over a broad area (all across steeply dipping rocks) also indicates a former erosion plane.

We do recognise patches of *Lithothamnium* incrustation in places, but so far I have never found even the relic of the raised marginal rim which is so characteristically associated with the contemporary reef ; which is hardly surprising since the outermost edge would be the first to suffer active erosion with emergence.

On the other hand, we recognise "fossil " blowholes, " fossil " cliffs and the former under-cuts or notches at the bases of these cliffs. All these features, of course, are in varying stages of degradation.

Three characteristic emerged platforms with their associated beach accumulations may be observed at approximately 10, five and two feet above datum (*see* text fig. 8 and 9). It is unusual to find all three preserved in one and the same place for the obvious reason that the formation of each younger one tends to destroy the immediately preceding one. On the other hand, around the limited compass of the Point Peron peninsula, all three are found in varying conditions of preservation.

In age, the 10-foot platform is the oldest, while the five- and two-foot platforms represent intermediate still-stands of the sea in its drop to the present level. From the dimensions of the 10-foot platform and of the contemporary reef, we may presume that these features were formed during long periods of stable sea-level, while the five- and two-foot platforms, being very much smaller than either the oldest or the present features, must have represented relatively brief periods of stability.

The fact that the low cliffs between the respective platforms are even preserved almost intact as steep abrupt features, clearly indicates that the sea-level changes between the periods of stability were accomplished with great rapidity, allowing only a minimum of time in which intermediate erosion could take place. Had the sea-level been gradually lowered over a long period, we would expect a broad sloping bench rather than a series of short sharp steps.

Text fig. 8.

Three former marine benches cut in the Pleistocene eolianite, dipping steeply landwards Locality just south of Point Peron itself. Man is standing on the lower part of the notch—of the 5-foot bench and is indicating the rather worn surface of the 10-foot level. The 2-foot level in the foreground is partly obscured by beach sand and plastered by contemporary beach-rock. The sea is nearly at low tide.

Text fig. 9.

Former notch cut in indurated eolianite and filled with beach-rock conglomerate and shell plasters of the 5-foot sea-level, exposed in vertical section by quarrying just north of Fisherman's Head and producing the paradoxical situation of a younger deposit almost completely enclosed in undisturbed older rocks

Detailed features of the respective platforms are as follows :—

(i) *Ten-foot Platform.*—This is the highest platform encountered at Point Peron, or, for that matter, anywhere so far in the Coastal Limestone rocks of Western Australia. It is found very well preserved around the Point Peron peninsula at a number of points : 150 yards South-East of Point John in a small protected cove ; at Fisherman's Head (200 yards South-West of Point John) ; 150 to 250 yards South of Fisherman's Head ; bevelling some earlier beach-rock at the northern end of Long Reach; on the North and South sides of Point Peron itself ; 100 to 200 yards South-East of Point Peron and on the pointed headland between Haliotis Bay and the northern end of Shoalwater Bay.

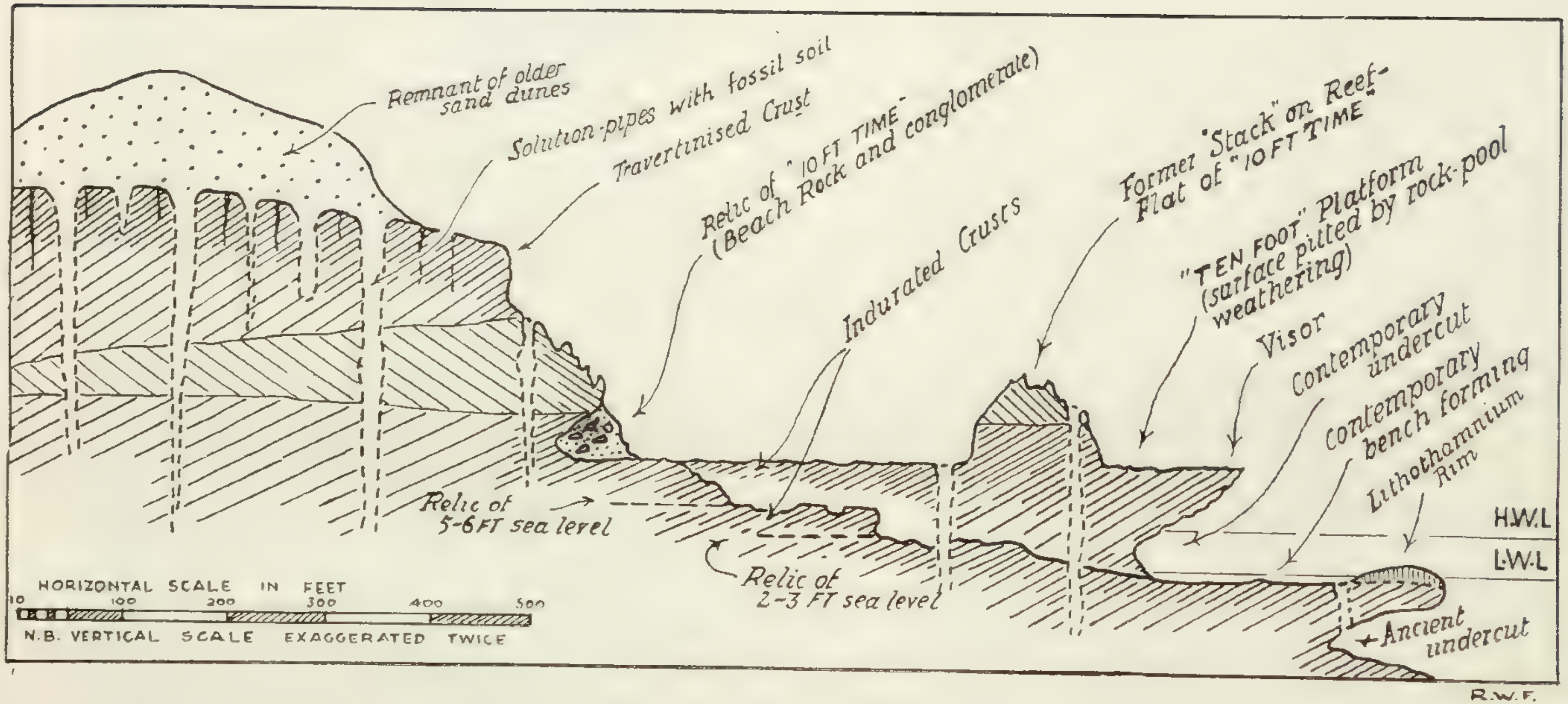
All these traces of the 10-foot platform are all the more impressive because they truncate the steeply dipping eolian bedding of the Coastal Limestone, and there is thus no chance of differential weathering producing apparent platforms which are not true products of former high sea-levels.

Certain of these 10-foot benches, as for example at Fisherman's Head, are subject to contemporary pool-level weathering (by spray-filled rock basins). However, this type of weathering has not carried the surface of the platform down more than two or three inches. The nature of this process has recently been described in California by Emery (1946).

Elsewhere, only rainwater and spray are apparent as erosive forces. These tend to cut up the surface of the platform into short sharp jagged pinnacles, but, nevertheless, it is still surprising how relatively unaffected many of these platforms are by erosion since the time they first rose above low tide level some thousands of years ago.

Text fig. 10.

Fisherman's Head, looking north-west, showing the 10-foot bench, crowned by honeycombed pinnacles representing former sea stacks. The cross-bedding of the eolianite (dipping landwards at 20°) may be seen running right through the whole cliff. In this exposed position all traces of the 5- and 2-foot benches have been effaced in one big contemporary notch, while blocks of the formerly overhanging " visor " have fallen down in the right-hand side. There is about one foot of water on the reef.



Text fig. 11.

Idealized section through Fisherman's Head, indicating the relationship between the four marine benches (contemporary, 2-foot, 5-foot and 10-foot) which bevel the old eolianite. Associated with them are under cut notches and their contemporary beach deposits. The problematical "ancient undercut," beneath the present sea-level, is also indicated. Note how the cross-bedding in the eolianite and the vertical solution pipes (reaching below sea-level) are older and independent of any of the benches.

At Fisherman's Head, and in a more dissected way at Point Peron itself, there are former sea-stacks which existed somewhat in their present form, even at the time of the 10-foot level. In this way the stacks at Fisherman's Head are seen rising up (with slightly under-cut sides in places) from the 10-foot platform for another 10 feet or so. Again, the cross-bedding of the eolianite may be seen running up into the stack (*see* text figs. 10 and 11).

The impressive development of beach-rock, rising from several feet below sea-level to be bevelled off at 10 feet above, found in Long Reach, is probably attributable to the period of rising sea-level immediately preceding this 10-foot period. The situation there is complicated by the plastering of more recent beach-rocks on the surface of the old in places.

(ii) *Five-foot Platform.*—With this lower platform we are already within reach of direct wave action when the tide is at its highest and the waters reach of a direct wave action when the tide is at its highest and the waters of the continental shelf are banked up by on-shore storms, so that the highest waves and swash may actually attack the five-foot platform. The tendency, therefore, is for this platform to be more dissected, curiously enough, than the older 10-foot platform.

In any case, however, as indicated above, it is a platform of much smaller extent than the 10-foot and is consequently more easily effaced. Nevertheless, it is found at a number of places on the Point Peron peninsula : 75 yards South-West of Point John ; 20 to 50 yards North-East of Fisherman's Head ; in traces 200 yards South of Fisherman's Head ; bevelling outcrops of old beach-rock at Long Reach, on both sides of Point Peron itself and on both sides of Haliotis Bay.

The finest occurrences are thus on either side of Point Peron itself, which, for some reason, appears to be more protected than elsewhere. These are amongst the best preserved traces of the five-foot sea-level of the mainland of Western Australia, though much more extensive traces of it are found at Rottnest (Teichert, 1950) and the Abrolhos Islands (Fairbridge, 1948). At Point Peron it is found cutting into the edge of the 10-foot platform with a nicely developed under-cut, but is generally only about three to 20 feet in width.

No emerged shell beds or beach-rock have been so far actually identified with this platform at Point Peron except for one small patch South-East of Fisherman's Head where quarrying activities have apparently removed the five-foot platform. Plastered into under-cuts and crevices in the eolianite to the interior there is a typical shell deposit of the type commonly associated with pockets of beach-rock (*see* text fig. 9). Owing to the removal of the platform which formerly lay in front of this under-cut, these shell deposits today appear in a very paradoxical position, since they are both overlain and underlain by diagonally bedded eolianite and at first sight appear to be intercalated stratigraphically in that eolianite, for their grain-size and cement is practically identical. Only careful examination discloses that, in fact, we have only a shell "plaster."

(iii) *Two-foot Platform.*—The traces of this most recent intermediate still-stand come well within the compass of the present tidal range and are thus almost daily subjected to wave attack (both chemical and physical). It is not, therefore, in the least surprising that the relics of this bench are very obscure except in the most protected places.

Were it not for the fact that we recognise traces of this sea-level very clearly in Rottnest, the Abrolhos and elsewhere on this Western Australian

coast, it might be easy to pass over the evidence at Point Peron without noticing it ; nevertheless, there are certain traces of conformable levels which occur undeniably at this elevation here, especially to the North-East side.

Associated with this level, particularly at Haliotis Bay and Long Reach, there appear to be some formations of beach-rock which are unquestionably younger than the eolianite and yet rise to a height somewhat above contemporary limits of beach-rock formation (*see* Sec. II (c)).

(c) Shore Ramps.

In most places along the coast the junction between the horizontal contemporary shore platform and the shore itself is marked by a low undercut cliff or by a sloping sandy beach. However, in certain places such as Haliotis Bay and certain spots on Rottnest, there is short ramp, which is bevelled across the bedding planes of the eolian rock material.

This sloping ramp is a feature which does not seem to have been described before and its origin is rather puzzling. It slopes down from high to low tide level at a more or less uniform angle and then flattens out sharply where it joins the horizontal platform. Above high tide it either merges with a five-foot platform or passes into an under-cut cliff. The angle of the ramp is generally identical with that of neighbouring beach-sands and therefore appears to be a function of the local factors of wave erosion, exposure, etc. In some places the upper limits of the ramp are pock-marked by rain water and spray erosion, and in certain places the lower part of the ramp is being under-cut and dissected with radial channels by marine attack, but the ramp appears to be quite smooth where it has been only recently exposed. It appears to disappear laterally beneath adjacent sand beaches, or into beach-rock.

It may be seen thus that where exposed to continued erosion, either subaerial or marine, the ramp quickly begins to disintegrate. On the other hand, it is not to be confused with a recently cemented accumulative deposit, as for example, a contemporary beach, because we may recognise across the smooth surface of the ramp the basset edges of the truncated eolianite bedding planes.

The impression I have gained, therefore, is that it is an erosion surface which is a function of the local swash zone.

(d) Beaches, Beach-rock, Spits and Dunes.

Contemporary sand-beaches at Point Peron are somewhat restricted except in Long Reach, the broad sweep between Point Peron itself and the cliffs South of Fisherman's Head, and a shorter stretch at Haliotis Bay. Further sand accumulations occur along most of the North-East shore from Point John to Rockingham and beyond, and in the South forming the shore of Shoalwater Bay. The beaches are fairly gentle for the most part and rise sharply inland into dunes. Beach gradients range from seven down to about three degrees.

Contemporary beach-rock appears to be forming today in the normal manner experienced on tropical and warm-temperate calcareous beaches. It is found in Long Reach and Haliotis Bay in particular. On the long sandy sweeps to the East and South, however, it is notably absent. Where it does occur it should be restricted in height in its contemporary development, almost precisely to the limits of the intertidal belt, and thus with the small

tidal range at Point Peron could not theoretically have a maximum thickness of more than four to five feet. However, on examination it was found to extend from a few feet below sea-level to somewhat more than 10 feet above low water mark.

Since the beach-rock extends through a vertical elevation of about 12 to 15 feet, it must be assumed that it represents beach formations, formed through a period of changing sea-level, since there is no reason on an open coast like this to assume any fundamental change in tidal characteristics, which, as noted above, would not permit more than four to five feet of beach-rock to form at any one stand of the sea-level. It appears, therefore, that this formation represents a series of beach-rocks which were laid down in bays in the former dune coast, probably during the rise of the sea-level at the beginning of Recent times. Similar examples are to be seen on Rottnest Island and elsewhere along our coast.

Turning now to the sand spits which are another interesting feature of the Point Peron coast, we may comment that they generally tend to develop in the vicinity of islands and headlands where intersecting series of waves tend to "shepherd" sand out into long tongue-like projections. In this way, sand from the beaches of Mangle's Bay is migrating steadily out to the North-West in response to waves which have swung round in the South-West part of the Bay, to break in the opposite direction to the waves coming from the ocean side, *i.e.*, from the West. Representatives of these in their reduced intensity curl around Point John and intersect with the Mangle's Bay wave system about half a mile South East of Point John opposite a slight irregularity in the sweep of the Bay. Once initiated, sand-banks of this type tend to evolve to considerable dimensions, and in this manner a broad sandy spit has now grown out from the shore for over 400 yards in a northerly direction.

Traces of submerged sand spits may be recognised from the air-photographs at various points to the South in Shoalwater Bay, connecting Safety Bay with Penguin Island and separating Peel Harbour from Warnbro Sound (about half a mile South of Safety Bay and four miles South of Point Peron). An interesting historical record refers to these old sand spits which separate Peel Harbour from Warnbro Sound. Peel Harbour was originally surveyed more than a century ago as a suitable loading point for timber ships, but an extraordinary change in the sand spits which formerly protected it from southerly gales rendered this project impossible. The surveyor, J. S. Roe, reported to the Colonial Secretary in 1846, that in the 10 years since the former survey in 1837, a considerable change in the coastline had taken place; whereas Peel Harbour had been protected from Warnbro Sound by a scrub-covered sandy spit, it was then (in 1846) practically cut off by an extension of this sand barrier over the floor of the Harbour where there had been previously 10 fathoms of water. Of this protection and obstruction there is now but little trace except as may be recognised under water from the air-photographs.

Peel Harbour is today in direct connection with Warnbro Sound and is totally exposed to southerly storms. The air photographs, however, clearly show traces of sand spits extending from the shore about one mile East of Safety Bay township in a south-westerly direction, and these are apparently the sites of the former promontories and spits. It is notable that they represent extensions in the trends of the old beach-ridges on the landward side (*see* below under Sec. III (e)).

Contemporary dunes have been developed and are being actually augmented both on the headland of Point Peron and at many points behind

the beaches of Shoalwater Bay and elsewhere along the coast. These dunes are overwhelming and obscuring the pre-existing system of beach-ridges. At Point Peron the dunes rise to 88 feet and further South still higher. The dunes reflect the prevailing wind (South-West) in the general way, being of the parabolic "blow-out" type, pointing more or less to the North-East.

(e) Old Beach-ridges.

As remarked in Section II (c) of this paper, no recently formed beach-ridge has been positively identified at Point Peron or vicinity, but an enormous series of beach-ridges may be followed from the peninsula, stretching away to the next line of limestone hills, about five miles to the East, forming a wide flat plain covered by steep little ridges and swales.

The bulk of the beach-ridges have been measured and range from about 10 to 15 feet above datum in the swales to 20 to 30 feet on the crests. It would appear from these figures that most of the ridges developed during the 10-foot sea-level, when ordinary wave action would build up beaches of seven to 10 feet above that level and additional assistance by winds would account for the rise to 20 feet (above the 10-foot datum) and even higher in isolated cases.

The level of this plain does not appear to drop (according to military surveys) in any noticeable manner in the five miles from the interior to the exterior, and beach-ridges may thus have developed during the long period of stable high sea-level, 10 feet above the present, though on the Cockburn Sound side the outermost ridges are somewhat lower and may have developed during the lower intermediate sea-levels at five and two feet. Further study of this problem might prove instructive.

Study of the air photographs discloses very interesting patterns in these old beach-ridges. It is found that the bulk of the ridges are parallel to old limestone hills and shore-line which lay five miles East of Point Peron, each successive ridge following the former at about 50 to 100 yards. Without counting them carefully, this would make between 80 and 100 beach-ridges across the plain.

In the triangle between Point Peron, Rockingham and Safety Bay, however, the parallelism of the main beach-ridge pattern begins to show interruptions, apparently due to the intersection of the wave systems, on the one hand from Warnbro Sound in the South, and on the other from Shoalwater Bay to the West. As noted above, a lower and somewhat reduced system of beach-ridges is also found forming a belt between one quarter and one half a mile in width around Rockingham forming the southern limits of Mangle's Bay (Cockburn Sound). The three systems reflect somewhat the wave symmetry between West, North and South.

Where these three systems intersect there is a certain amount of erosional truncation of one beach-ridge system by another, and finally in the middle there is a depression occupied by a broad swampy lake (Lake Richmond). Today this lake is fairly fresh, but this may be explained in the light of the high rainfall in this area and the fact that the fresh water table beneath this plain lies at an average depth of less than 10 feet. The level of the lake is generally about six feet above datum, and its floor is at least 10 to 15 feet below. This fact, with the lower beach-ridge pattern to the north, and its calm-water marine fossils (*see* Sec. II., (e)), all go to suggest that the lake was formerly a bay open to the north.

It is to be noted from the attached map (text fig. 1) that the beach-ridge patterns are truncated by the coast in the south-western part of Mangle's Bay, in the middle part of Shoalwater Bay and in the northern part of Warnbro Sound, and it appears that considerable sections of the sandy coastline in these areas have been washed away during the last few thousand years, that is to say, during the period of the Recent successive drops in sea-level.

In a few places contemporary sand dunes are overwhelming the old beach-ridges and everywhere the old ridges are thoroughly overgrown by scrub and even trees. It appears certain, therefore, that no beach-ridge formation is taking place today, and, furthermore, that active erosion of beach-ridges has been taking place for a considerable number of years.

IV.—CONCLUSIONS.

We have seen how the whole of Point Peron and a broad plain connecting it with the limestone hills five miles to the East, on which stand the towns of Rockingham and Safety Bay, are entirely made up of Pleistocene and Recent sediments. The oldest rock type is the Pleistocene calcareous eolianite, the Coastal Limestone, overlain by beach sand, beach-ridge and dune deposits of various ages in the successive post-Pleistocene cycles of sedimentation.

The present limestone shore is bevelled by broad marine platforms forming at low water level today, and the shores are terraced by relics of earlier Recent sea-levels forming platforms or benches at two, five and 10 feet above present datum and associated locally with contemporary shell beds.

Especially interesting features described, include the particular physiographic features of the contemporary reefs and the emerged platforms. The old beach-ridge pattern to be observed mainly from air photographs presents further valuable evidence on the subject of Recent history.

Recapitulating the geological history of the region, we find that two parallel systems of dune-rock formations, five miles apart, run in a more or less North-South direction (there are also parallel rows of dune rocks recognised further off-shore). These two dune systems were exposed to subaerial erosion in Late Pleistocene times and deeply indurated by circulating lime-rich solutions and intersected by complex karst erosion features. The whole landscape was then " drowned " by the early Recent transgression, commonly known as Flandrian transgression (of Dubois). The sea rose to 10 feet above its present low water stand, and since this phenomenon is recognised as a world-wide feature, we are able to compare its age with the accurate observations in Europe, which indicate the time to have been about 4,000 years ago. The sea remained at this level for many hundreds of years, during which time the old limestone hills of hardened eolianite were subjected to wave erosion and benched by horizontal platforms. The shallow sea between the range of limestone hills, of which Point Peron was one, and the inner range lying East of Rockingham became gradually silted up with deposits of sand, and during this long period of stable sea-level, row after row of long beach-ridges grew up in front of the eastern row of hills until, finally, Point Peron and other remnants of the western row of hills became joined to the newly formed plain of beach-ridges in the manner of tombolos.

The level of the sea then dropped sharply in two steps ; first to five feet and then to two feet, during which time the limestone shores of Point Peron and its adjacent islands or headlands became further benched by the

marine terraces of the time. Finally, it seems, about 2,000 years ago, the sea-level again became stabilised and this time at about its contemporary level. Since then extensive benching of the limestone shores has taken place, so that there are now wide contemporary reef flats, and considerable erosion of the soft beach-ridge country, where it is unprotected by the limestone hills in front, has resulted in the introduction of broad sweeping sandy bays backed by steep sand hills and the truncated ends of the old beach-ridges.

As a result of this fairly complex geologic and geomorphological history we may see that the character of the shore-line around Point Peron, including the broad sweeps of Mangle's Bay and Warnbro Sound, must be regarded as *compound*, following Douglas Johnson's scheme (1919). As a matter of fact, Johnson's theoretical conclusion that four fundamental shore-line types may exist, *i.e.*, emergent, submergent, neutral and compound, is a somewhat hypothetical one, since, owing to the complex eustatic oscillations which have occurred right up until very Recent times and may even be still in progress today, no shore-line may be regarded as anything but compound, when carefully examined, unless it be a brand-newly exposed volcanic island or a recently accumulated sandbank or an equally recent shore produced in the unstable volcanic belts ; even the rapidly rising isostatic shores of Scandinavia and North America exhibit evidence of eustatic reversals.

We see, therefore, that the Point Peron coastline is in many ways similar to other stable coastlines which have been subject to Quaternary eustatic oscillations. Here we have evidence, first of extensive emergence followed by widespread "drowning," a submergence which took the sea far inland behind the present shore-line, and then a progressive emergence, which occurred step by step, almost up to the present day. The character of this emergence has not been a steady one, however, but rather spasmodic, when long periods of stable sea-level were interrupted by short periods of rapidly changing sea-level. This is shown by the fact that we have horizontal benches separated by short sharp cliffs.

The time occupied by these rapid changes must have been quite remarkably short. There has been much recent research on these matters in Scandanavia which may now provide a more absolute dating by means of levelling, varve analysis, archaeology and palaeontology, all uniting to give accuracy to the Late-Quaternary geologic events. Florin (1944) has demonstrated that one of the early Recent rises of sea-level took place at the rate of about 25 mm. per year, thus much faster than the one millimetre per year rise that may be going on today, according to Gutenberg and others (*see* Fairbridge, 1947 (b)). A change of sea-level at the rate of 25 millimetres (about one inch per year) would enable the change from our 10-foot to five-foot level to be accomplished within a span of only 60 years.

The periods of stability on the other hand, during which broad horizontal limestone platforms could be eroded, must certainly have lasted for many hundreds of years. Judging from the width of the benches (especially on Rottnest, where they are better preserved than on Peron), the 10-foot must have been the longest, requiring perhaps 1,000 years, while the intermediate levels lasted but a few centuries each.

The remarkable stability of the sea during these periods (necessary to produce absolutely horizontal platforms), in contrast to the obvious rapidity of the transitions from one level to the next, raises major questions of geology. We appear to find evidence here against gradual cyclic changes of sea-level, of a type which might be controlled by astronomic-meteorologic causes, and turn to spasmodic "catastrophic" changes of perhaps geotectonic origin.

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APPENDIX I.

MOLLUSCA, ETC.

The following is a brief analysis of the main representatives of mollusca and other shelly marine invertebrates found about Point Peron, either on the contemporary beaches, in off-shore dredgings, or in the 10 to 24 foot raised beach just South of the Point itself (taken to be "early" Recent). For sake of interest, species common also to the late Pleistocene marine horizon at Peppermint Grove are also indicated. The bulk of the Peppermint Grove fauna is not, however, represented at all at Point Peron. The friendly assistance of Mr. B. C. Cotton, of Adelaide, in identifying much of this material is gratefully acknowledged.

It should be noted that the contemporary suite from Point Peron was collected from *both* sides of the headland, that is to say from two extremely different habitats . that on the West. being one of reefs and rocky shores (mainly gastropods and echinoids) : that on the East being one of sandy beaches or muddy flats (mainly pelecypods). The absence of pelecypoda, save for the single form *Barbatia pistachia*, from the Peron raised beach clearly indicates its limited environment, while the discovery of *Katelysia scalarina*, etc., in what appear to be raised beach deposits of similar age near Lake Richmond, suggests that here, in contrast, there was a protected bay. The raised beaches on the East side of Garden Island are likewise rich in bivalves. The late Pleistocene Peppermint Grove beds appear to be somewhat mixed in character.

As regards the taxonomy, it may be seen that since the last general check-list of West Australian mollusca was published by Hedley (1916) there have been numerous generic or subgeneric changes, and some of these have been indicated. The specific names, however, have only changed in a few instances.

A.—Living: Point Peron, Garden Island and vicinity.
B.—10 to 24 foot Raised beach, Point Peron.
C.—Late Pleistocene, Peppermint Grove.

	A.	B.	C.
PELECYPODA.			
Family—Amphidesmatidae			
Amphidesma cuneata (Lamarck, 1818). (= *Crassatella*)	x		
Family—Anomiidae			
Monia ione Gray, 1849	x		
Family—Arcidae			
Acar laminata Angas, 1865. (= *Arca*)	x		
Barbatia pistachia (Lamarck, 1819). (= *Arca radula*; *A. fasciata*)	x	x	
Family—Cardiidae			
Cardium racketti Donovan, 1826	x		
Cardium cyngorum Deshayes, 1855	x		
Cardium imbricatum Sowerby, 1841	x		
Cardium foveolatum Sowerby, 1841	x		
Family—Carditidae			
Cardita crassicosta Lamarck, 1819	x		
Cardita incrassata Sowerby, 1825	x		
Family—Chamidae			
Chama ruderalis Lamarck, 1819	x		
Family—Cleidothaeridae			
Cleidothaerus albidus (Lamarck, 1819) (= *Chama*)	x		
Family—Crassatellitidae			
Eucrassatella pulchra (Reeve, 1842)	x	....	x
Family—Donacidae			
Deltachion chapmani Gatliff and Gabriel, 1923	x		
Family—Glycymeridae			
Glycymeris (*Veletuceta*) *striatularis* (Lamarck, 1819) (= *Pectunculus*)	x		
Family—Hiatellidae			
Hiatella australis Lamarck, 1822	x		
Family—Leptonidae			
Ephippodonta macdougalli Tate, 1888	x		
Myllita deshayesi d'Orbigny and Recluz, 1850	x		
Family—Limidae			
Austrolima gemina Iredale, 1929	x		
Limatula strangei Sowerby, 1872	x		
Family—Lucindae			
Divalucina occidua Cotton and Godfrey, 1938	x		
Cavatidens perplexa Cotton and Godfrey, 1938	x		
Family—Mactridae			
Austromactra cumingi (Reeve, 1854) (= *M. cuvieri*)	x		
Austromactra australis (Lamarck, 1818)	x		
Electromactra flindersi Cotton and Godfrey, 1938	x		
Lutraria rhynchaena Jonas, 1844	x		
Family—Mytilidae			
Brachyodontes erosus (Lamarck, 1819) (= *Mytilus*)	x	....	x
Modiolus albicostus Lamarck, 1819	x		
Mytilus planulatus Lamarck, 1819	x		
Family—Ostreidae			
Ostrea sinuata Lamarck, 1819 (= *O. angasi* Sowerby, 1871)	x		
Saxostrea gradiva Iredale, 1939	x		

APPENDIX I.—*continued.*

	A.	B.	C.
PELECYPODA—*continued.*			
Family—Pectinidae			
Mimachlamys asperrimus (Lamarck, 1819) (= *Pecten*)	x	...	x
Mimachlamys australis (Sowerby, 1847) (= *Pecten*)	x		
Notochlamys anguineus (Finlay, 1926) (= *Chlamys*)	x		
Notovola alba (Tate, 1887) (= *Pecten*)	x		
Family—Pholadidae			
Pholas australasiae Sowerby, 1814	x		
Family—Pinnidae			
Pinna dolabrata Lamarck, 1819	x		
Family—Psammobiidae			
Flavomala biradiata (Wood, 1815) (= *Solen*; *Gari*; *Soletellina*)	x	...	x
Family—Solemyidae			
Solemya australis Lamarck, 1818	x		
Family—Spondylidae			
Spondylus tenellus Reeve, 1856	x		
Family—Tellinidae			
Macoma deltoidalis Lamarck, 1818	x		
Pseudarcopagia victoriae Gatliff and Gabriel, 1914	x		
Salmacoma inequivalvis (Sowerby, 1867) (= *S. beryllina*)	x		
Tellina perna Spengler, 1798	x	....	x
Family—Veneridae			
Chioneryx cardioides (Lamarck, 1818)	x		
Dosinia victoriae Gatliff and Gabriel, 1914	x		
Gomphina undulosa (Lamarck, 1818) (= *Venus*)	x		
Katelysia peroni (Lamarck, 1818) (= *Venus*)	x		
Katelysia scalarina (Lamarck, 1818) (= *Venus*)	....	x	x
Macrocallista bardwelli Clench and McLean, 1936 (= *Paradione*)	x		
Placamen flindersi Cotton and Godfrey, 1938	x		
Proxichione laqueata (Sowerby, 1853) (= *Venus*; *Antigona*)	x	...	x
Sunemeroe vaginalis (Menke, 1843) (= *Cytheria*; *Sunetta*)	x		
Tawera lagopus (Lamarck, 1818)	x		
Venerupis crenata Lamarck, 1818	x		
Venerupis exotica Lamarck, 1818	x	....	x
Family—Vulsellidae			
Malleus meridianus Cotton, 1930	x		
GASTROPODA.			
Family—Acmaeidae			
Notoacmea septiformis (Angas, 1865) (= *Acmaea*, *Patelloida*)	x		
Patelloida alticostata (Angas, 1865) (= *Patella*)	x	x	x
Patelloida nigrosulcata (Reeve, 1855)	x		
Family—Buccinidae			
Cominella eburnea (Reeve, 1846) (= *Buccinum*)	x		
Josepha tasmanica (Tenison-Woods, 1879) (= *Cominella suturalis*; *C. tasmanica*)	x	x	x
Niotha pyrrhus Menke, 1843	x		
Family—Bullidae			
Bullaria tenuissima (Sowerby, 1868) (= *Bulla*)	x	....	x
Family—Calyptraeidae			
Sigapatella hedleyi Smith, 1915	x		
Zeacrypta immersa (Angas, 1865) (= *Crepidula*)	x		
Family—Cancellariidae			
Nevia spirata (Lamarck, 1822) (= *Cancellaria*)	x		
Family—Cerithiidae			
Ataxocerithium serotinum (Adams, 1855) (= *Cerithium*)	x		
Cacozeliana granarium (Kiener, 1842) (= *Cerithium*)	x	x	x
Campanile laeve (Quoy and Gaimard, 1834) (= *Cerithium*; *Ceratoptilus*)	x	x	
Pseudovertagus aspera Linne, 1758	x		
Family—Conidae			
Floraconus anemone (Lamarck, 1810) (= *Conus*)	x	x	x
Family—Cymatiidae			
Charonia rubicunda (Perry, 1811) (= *Cymatium lampas*)	x		
Mayena australasia (Perry, 1811) (= *Cymatium australasia*)	x	x	
Negyrina subdistorta Lamarck, 1822	x		
Family—Cypraeidae			
Ornamentaria annulus (Linné, 1758) (= *Cypraea*)	x		
Ravitrona caputserpentis (Linné, 1758) (= *Cypraea*)	x	x	x
Zoila friendii (Gray, 1831) (= *Cypraea*)	x		
Family—Fissurellidae			
Austroglyphis lincolnensis (Cotton, 1930) (= *Diodora*)	x		
Entomella candida (Adams, 1852) (= *Emarginula*)	x		
Scutus anatinus (Donovan, 1820) (= *Patella*; *Parmophorus*)	x		
Sophismalepas nigrita (Sowerby, 1835) (= *Lucapinella*; *Fissurella*)	x		
Family—Gadiniidae			
Gadinia albida Angas, 1867	x		
Family—Haliotidae			
Marinauris roei (Gray, 1826) (= *Haliotis*)	x		
Marinauris scalaris (Leach, 1814) (= *Haliotis*)	x		
Sanhaliotis elegans (Koch, 1844)	x		
Family—Hipponicidae			
Antisabia erma Cotton and Godfrey, 1938	x	x	
Sabia conica (Schumacher, 1817) (= *Amalthea*; *Hipponix*)	x	x	
Family—Ianthinidae			
Ianthina violacea Linné, 1758	x		

APPENDIX I.—*continued.*

GASTROPODA—*continued.*	A.	B.	C.
Family—Littorinidae			
Melarhaphe unifasciata (Gray, 1826) (= *Littorina*)	x		
Family—Marginellidae			
Marginella ovulum (Sowerby, 1846)	x	x	x
Family—Mitridae			
Mitra glabra (Swainson, 1821)	x	....	x
Vicimitra rhodia (Reeve, 1845) (= *Mitra*)	....	x	
Vicimitra rosetti (Angas, 1865)	x		
Family—Muricidae			
Bedeva assisi (Tenison-Woods, 1877) (= *Trophon*)	x		
Emozamia flindersi (Adams and Angas, 1863)	x		
Rapana mira (Cotton and Godfrey, 1932)	x		
Family—Nassariidae			
Nassarius particeps (Hedley, 1915)	x		
Parcanassa Pauperata (Lamarck, 1822) (= *Buccinum*)	x		
Family—Naticidae			
Friginatica beddomei (Johnston, 1884) (= *Natica*)	x		
Notochlis sagittata (Menke, 1843) (= *Natica*)	x		
Propesinum pictum (Recluz, 1843) (= *Sinum*)	x		
Uber conicum (Lamarck, 1822) (= *Natica; Polinices*)	x	x	x
Uber plumbeum (Lamarck, 1822)	x		
Family—Neritidae			
Melanerita melanotragus (Smith, 1884) (= *Nerita*)	x	x	
Nerita lineata (Gmelin, 1791)	x	x	
Family—Olividae			
Oliva australis Duclos, 1835	x	....	x
Family—Patellidae			
Cellana limbata (Phillipi, 1849) (= *Patella*)	....	x	
Cheilea occidua (Cotton, 1935)	x	x	
Patellanax squamifera (Reeve, 1855) (= *Patella*)	x		
Family—Philinidae			
Philine angasi (Crosse and Fischer, 1865)	x		
Family—Pyrenidae			
Euplica bidentata (Menke, 1843) (= *Columbella, Pyrene*)	x		
Family—Scalidae			
Clathrus jukesiana (Forbes, 1852) (= *Scalaria, Epitonium*)	x		
Scala imperialis (Sowerby, 1844) (= *Scalaria*, = *Epitonium*, = *Clathrus*)	x		
Family—Siphonariidae			
Siphonaria baconi Reeve, 1856	x		
Family—Stomatiidae			
Stomatella imbricata Lamarck, 1816	x		
Family—Strombidae			
Doxander campbelli (Griffiths and Pidgeon, 1834) (= *Strombus*)	x		
Family—Thaidae			
Dicathais aegrota (Reeve, 1846) (= *Purpura textilosa; P. aegrota; Thais textilosa*)	x	x	x
Family—Tonnidae			
Tonna variegata (Lamarck, 1822) (= *Dolium*)	x	....	x
Family—Trochidae			
Angaria tyria (Reeve, 1842) (= *Delphinula*)	x		
Austrocochlea rudis (Gray, 1847) (= *Monodonta*)	x		
Cantharidus lehmanni (Menke, 1843) (= *Trochus*)	x		
Euriclanculus personatus (Phillipi, 1847)	x	x	
Gibbula lehmanni (Menke, 1843) (= *Turbo; Prothalotia*)	x		
Herpetopoma aspersa (Phillipi, 1846) (= *Trochus*)	x		
Isoclanculus yatesi (Crosse, 1863) var. *ringens* (Menke, 1843)	x		
Mesoclanculus consobrinus (Tate, 1893) (= *Clanculus*)	x		
Mesoclanculus denticulatus (Gray, 1826) (= *Monodonta*)	x		
Phasianotrochus eximius (Perry, 1811)	x		
Phasianotrochus irisodontes (Quoy and Gaimard, 1834) (= *Trochus; Cantharidus*)	x		
Tallopia callifera (Lamarck, 1822)	x		
Thalotia conica (Gray, 1847) (= *Monodonta; Thalotia woodsiana; Cantharidus*)	x	x	x
Family—Turbinidae			
Bellastrea squamifera (Koch, 1844) (= *Astraea fimbriata; Trochus*)	x		
Mimelenchus ventricosa (Swainson, 1822) (= *Phasianella ventricosa; P. perdix*)	x		
Ninella torquatus (Gmelin, 1791) (= *Turbo stamineus* Martyn, 1784)	x		
Phasianella australis (Gmelin, 1788) (= *Buccinum*)	x		
Senectus intercostalis (Menke, 1843) (= *Turbo pulcher*)	x	x	x
Family—Turridae			
Zemitrella lincolnensis (Reeve, 1859) (= *Lachesis; Fusinus*)	x		
Zemitrella austrina (Gaskoin, 1852)	x		
Family—Vermetidae			
Siliquaria australis Quoy and Gaimard, 1834	x		
Vermicularia sipho (Lamarck, 1818) (= *Serpula*)	x	x	
Family—Volutidae			
Amoria pallida (Gray, 1834) (= *Voluta volva; Scaphella*)	x		
Melo miltonis Gray, 1834 (= *Amoria, Scaphella*)	x		

APPENDIX I.—*continued.*

CEPHALOPODA.	A.	B.	C.
Sepia (*Amplisepia*) *apama* Gray, 1849	x	x	
Sepia (*Arctosepia*) *braggi* Verco, 1907	x		
Sepia (*Mesembrisepia*) *chirotrema* Berry, 1918	x		
Sepia (*Decorisepia*) *cottesloensis* Cotton, 1929	x		
Sepia (*Solitosepia*) *glauerti* Cotton, 1929	x		
Sepia (*Glyptosepia*) *hedleyi* Berry, 1918	x		
Sepia (*Solitosepia*) *hendryae* Cotton, 1929	x		
Sepia (*Mesembrisepia* ?) *irvingi* Meyer, 1909	x		
Sepia (*Mesembrisepia*) *novaehollandiae* Hoyle, 1909	x		
Sepia (*Solitosepia*) *occidua* Cotton, 1929	x		
Spirula spirula Linné, 1758	x	x	
ECHINODERMATA. —ECHINOIDEA.			
Amblypneustes formosus Valenciennes, 1846	x		
Amblypneustes leucoglobus Döderlein, 1914	x		
Amblypneustes ovum (Lamarck, 1816)	x		
Amblypneustes pallidus (Lamarck, 1816)	x		
Breynia australasiae (Leach, 1815)	x		
Echinocardium cordatum (Pennant, 1777)	x		
Goniocidaris tubaria (Lamarck, 1816)	x		
Heliocidaris erythrogramma (Valenciennes, 1846) var. *parvispina* Clark, 1938	x		
var. *armigera* (Agassiz, 1872)	x		
Holopneustes inflatus Agassiz, 1872	x		
Holopneustes porosissimus Agassiz and Desor, 1846	x		
Peronella lesueuri (Agassiz, 1841)	x		
Phyllacanthus irregularis Mortensen, 1928	x		
Protenaster australis (Gray, 1851)	x		

NOTE.—Asteroidea, Crinoidea, etc., have not yet been studied.

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APPENDIX II.

FORAMINIFERA.

by W. J. PARR.

At the request of Dr. Rhodes W. Fairbridge, I have identified the foraminifera picked out by him and his students at the University of Western Australia, and have combined the results in the following table to show the distribution of the species in the different samples.

The foraminifera are from :—

Sample No. 1 .... Point Peron, modern beach sand.
,, No. 2 .... Naval Base P.O., modern beach sand.
,, No. 3 .... Trigg Island, modern beach sand.
,, No. 4 .... Rottnest (Geordie Bay), modern beach sand.
,, No. 5 .... Garden Island, modern beach sand.
,, No. 6 .... Geraldton Harbour, modern dredging.
,, No. 7 .... Point Peron, 10 to 24 foot raised beach.
,, No. 8 .... . . Point Peron, late Pleistocene eolianite.
,, No. 9 .... Trigg Island, late Pleistocene beach rock.
,, No. 10 .... Minim Cove Quarry, late Pleistocene marine band.
,, No. 11 .... Peppermint Grove, late Pleistocene "*Arca*" horizon.
,, No. 12 .... Peppermint Grove, late Pleistocene, current bedded marine band (10 feet below "*Arca*" band).

(In the following table, the frequencies of the occurrences are shown thus : c = common ; f = frequent; x = less than five specimens. (Except in columns 3, 9, 11 and 12, the frequency is not recorded.)

Species.	Sample No.											
	1	2	3	4	5	6	7	8	9	10	11	12
TEXTULARIIDAE—												
Textularia agglutinans d'Orbigny			f	x						x		
Textularia sp. aff. *conica* d'Orbigny	x		x	x								c
Textularia sp. aff. *pseudogramen* Chapman and Parr	x		x		x				c			
Textularia pseudotrochus Cushman									c			
VERNEUILINIDAE—												
Clavulina multicamerata Chapman	x	x		x		x						
Clavulina pacifica Cushman			x			x		x				
Cribrobulimina polystoma (Parker and Jones)	x					x						
Gaudryina (*Pseudogaudryina*) *hastata* Parr	x		x						x			
Gaudryina (*Siphogaudryina rugulosa* Cushman						x						
MILIOLIDAE—												
Hauerina fragilissima Brady										x	x	
Pseudomassilina agglutinans (Keijzer)						x						
Pyrgo sp.			x									
Pyrgo sp. (broad form)					x				x			
Pyrgo denticulata (Brady)									x			x
Pyrgo striolata (Brady)				x		x						
Quinqueloculina australis Parr			c	x	x			x				
Quinqueloculina baragwanathi Parr						x						x
Quinqueloculina bosciana d'Orbigny			c					x				
Quinqueloculina sp. aff. *bradyana* Cushman	x	x	f	x	x							
Quinqueloculina sp. aff. *costata* d'Orb			c		x	x		x		x		x
Quinqueloculina laevigata d'Orbigny						x						
Quinqueloculina lata Terquem			c		x			x				
Quinqueloculina lamarckiana d'Orbigny					x	x						
Quinqueloculina cf. *seminulum* (Linné)			x		x							x
Quinqueloculina subpolygona Parr	x		f			x	x					x
Quinqueloculina sp. aff. *vulgaris* d'Orbigny	x	x	c	x	x		x	x	x	x		
Spiroloculina sp.										x		
Spiroloculina antillarum d'Orbigny	x	x	x	x	x	x	x					
Spiroloculina milletti Wiesner						x				x		
Triloculina sp. nov.			c									f
Triloculina bassensis Parr			x		x		x					
Triloculina oblonga (Montagu)	x	x	x	x	x							
Triloculina rotunda d'Orbigny						x						
Triloculina striatotrigonula Parker and Jones			c		x	x			x			x
Triloculina subrotunda (Montagu)	x	x		x		x		x				x
Triloculina tricarinata d'Orbigny	x		c		x	x						f
Triloculina cf. *trigonula* (Lamarck)	x	x	x	x	x				c	x		

APPENDIX II.—*continued.*

Species.	Sample No.											
	1	2	3	4	5	6	7	8	9	10	11	12
OPHTHALMIDIIDAE—												
Nubecularia lucifuga Defrance	....	....	....	....	x							
Vertebralina striata d'Orbigny	....	....	....	....	x	x						
PENEROPLIDAE—												
Marginopora vertebralis Blainville	.	....	....	x	x	x	x	....	....	x		
Peneroplis pertusus (Forskal)		....	....	x	...	x						
Peneroplis planatus (Fichtel and Moll)	..	....	....	x	x	x	x	....	....	x		
Spirolina arietinus (Batsch)	...	....	....	....	....	x						
ALVEOLINIDAE—												
Alveolinella quoii (d'Orbigny)	.	....	....	....	....	x						
LAGENIDAE—												
Fissurina lacunata (Burrows and Holland)	..	...	..	..	....	x						
Lagena distoma-margaritifera Parker and Jones	x	...	x	...	...	x						
Lagena gracillima Sequenza	x	....	....	....	....	x						
Lagena semistriata Williamson	x	.	...	....	..	x						
Lagena sulcata (W. and J.) Williamson var. *interrupta*	..	.	.	...	..	x						
Oolina variata (Brady)	.	...	....	....	..	x						
Vaginulina patens Brady	...	....	....	....	....	x						
POLYMORPHINIDAE—												
Guttulina sp. no. 1	x											
Guttulina sp. no. 2		....	x									
Sigmoidella elegant sima (Parker and Jones)	.	....	x	x								
Sigmoidella kagaensis Cushman and Ozawa	....	....	....	x	....	....	....	....	x			
BULIMINIDAE—												
Bolivina abbreviata Heron-Allen and Earland	....	....	....	....	....	x						
Bolivinella sp. aff. *folim* (Parker and Jones)	x	...	...	...	....	....	....	x				
Bolivinita rhomboidalisu (Millett)	x	....	...	...	....	x						
Loxostomum limbatum (Brady)	....	....	..	....	....	x						
Pavonina flabelliformis d'Orbigny	x	....	....	x	....	x						
Reussella armata (Parr)	....	...	...	...	x							
Siphogenerina raphanus (Parker and Jones)	....	....	....	....	....	x						
Virgulina schreibersiana Czjzek	....	....	....	....	....	x						
SPIRILLINIDAE—												
Annulopatellina annularis (Parker and Jones)		....	....	...	....	x						
Spirillina inaequalis Brady		....	.	...	..	x						
DISCORBIDAE—												
Acervulina inhaerens Schultze	x	....	...	x	x	x						
Anomalina sp. nov.	...	....	....	....	....	....	....	...	f			
Cancris auricula (Fichtel and Moll)	.	....	....	....	....	x						
Cibicides lobatulus (Walker and Jacob)	x	x	x	....	....	x	...	...	....	..	....	f
Cibicides mayori (Cushman)	..	....	..	....	....	x						
Cibicides refulgens Montfort	x	x	f	x	x	x	x	x	f	x	c	
Discorbis sp. nov.		....	x									
Discorbis anglicus Cushman	.	....	....	....	...	x						
Discorbis australis Parr	x	....	....	...	....	x	x	...	....	x		
Discorbis dimidiatus (Jones and Parker)	x	x	c	x	x	x	x	x	c	x		
Discorbis dimidiatus (J. and P.) var. *acervulinoides* Parr	x	...	..	....	x	x						
Discorbis globularis (d'Orbigny)	....	....	x	....	....	....	...	....	x			
Discorbis cf. *mirus* Cushman	x	....	x	x	x	....	x					
Eponides repandus (Fichtel and Moll)	....	....	....	....	x	x						
Epistomaria polystomelloides (Parker and Jones)	....	....	x	....	....	x						
Glabratella pulvinata Brady	....	....	x									
Siphoninoides echinatus (Brady)	....	....	x	....	x	..	...	....	....	x		
GLOBIGERINIDAE—												
Globigerinoides sp.	....	....	...	...	....	....	...	....	....	...	..	x
Globigerina bulloides d'Orbigny	x	x	....	x	x							
Globigerina triloba Reuss	...	....	....	....	....	x						
GLOBOROTALIIDAE—												
Globorotalia menardii (d'Orbigny)	x	....	x									

APPENDIX II.—*continued.*

Species.	Sample No.											
	1	2	3	4	5	6	7	8	9	10	11	12
PLANORBULINIDAE—												
Miniacina miniacea (Pallas)	....	....	x									
Planorbulina acervalis Brady	....	....	....	....	x	x						
Planorbulina mediterranensis d'Orbigny	x	....	....	. . .	....	....	....	....	....	....	....	c
Planorbulina rubra d'Orbigny	....	....	x	x	x	x						
NONIONIDAE—												
Elphidium advenum (Cushman)	x	....	x	x	x	....	....	x	....	....	f	
Elphidium cf. craticulatum (Fichtel and Moll)	....	...	....	....	....	....	....	....	....	....	x	
Elphidium crispum (Linné)	x	x	....	x	x	....	....	....	....	x		
Elphidium sp. aff. *crispum* (Linné)	x	....	....	....	....	x	....	....	f			
Elphidium sp. aff. *incertum* (Williamson)	....	....	....	....	....	....	....	....	....	....	f	
Elphidium sp. aff. *macellum* (Fichtel and Moll)	x	. .	x	....	x	....	....	....	....	....	x	x
Elphidium milletti (Heron-Allen and Earland)	....	....	....	....	....	....	x					
Elphidium rotatum Howchin and Parr	...	...	....	....	x	x	....	....	....	....	x	
AMPHISTEGINIDAE—												
Amphistegina sp.	x	....	....	x	....	x						
Amphistegina quoii d'Orbigny	x	....	....	x	x	....	....	....	f	....	x	
ROTALIIDAE—												
Rotalia sp.	x	....	....	....	....	....	....	....	x			
Streblus beccarii (Linné)	....	....	....	....	....	x						
Streblus beccarii (Linné) var. cf. *tepida* (Cushman)	....	....	....	....	....	....	....	....	....	....	c	
Streblus sp. aff. *pauperatus* Parr	....	....	x									
CALCARINIDAE—												
Calcarina sp. nov.	x	....	....	.	x	..	x					
Calcarina stellata de Ferussac	....	....	....	....	x							
Calcarina cf. *venusta* Brady	x	....	x	....	....	x	....	x				

Notes on the foraminifera of the samples :—

The foraminifera in the samples from the vicinity of Perth are, with the exception of several new species, known Southern Australian shallow water forms, with some species which are typically of warmer water habitat. Species here recorded from these samples which are characteristic of the warmer coastal waters of Australia, are :—

Amphistegina quoii d'Orbigny.
Calcarina stellata de Ferussac.
Calcarina sp. cf. *venusta* Brady.
Clavulina pacifica Cushman.
Elphidium milletti (Heron-Allen and Earland).
Epistomaria polystomelloides (Parker and Jones).
Marginopora vertebralis Blainville.
Planorbulina rubra d'Orbigny.
Siphoninoides echinatus (Brady).
Textularia pseudotrochus Cushman.

The foraminifera from Geraldton, 300 miles North of Perth, show a greater proportion of Tropical species. Among those which do not occur in the other samples are :—

Alveolinella quoii d'Orbigny.
Loxostomum limbatum (Brady).
Pseudomassilina agglutinans (Keijzer).

On the other hand, there are two South Australian species, *Annulopatellina annularis* (Parker and Jones) and *Cribrobulimina polystoma* (Parker and Jones) which, at Geraldton, reach their most northerly known range.

The foraminifera in Samples Nos. 11 and 12, from Peppermint Grove, and No. 9, from the Late Pleistocene of Trigg Island, show some differences from those of the other samples. The two samples from Peppermint Grove are noteworthy for the absence of *Discorbis dimidiatus* (Jones and Parker), probably the most widely spread and characteristic foraminifera, which occurred in all of the other samples. The sample, No. 11, from the *Arca* horizon, shows the most striking differences from the other samples, and is distinguished by the abundance of *Streblus beccarii* (Linné), var. cf. *tepida* (Cushman). The variety *tepida* is a pauperate form which was described by Cushman from warm, shallow water in San Juan Harbour, Porto Rico. Apparently the conditions prevailing when the deposit forming the *Arca* horizon was laid down were different from those of the other deposits.

The foraminifera in the sample from the Late Pleistocene of Trigg Island are distinguished by the occurrence in numbers of what is probably a new species of *Anomalina*, and of *Textularia pseudotrochus* Cushman. The latter species is a common form on the Queensland coral reefs and I have not met with it elsewhere on the Australian coast. Apart from these two species, the Late Pleistocene deposit on Trigg Island is distinguished by the absence of *Quinqueloculina australis* Parr and an undescribed species of *Triloculina* with a rounded, flattened, faintly striate test, which is common on the coast of Victoria.

There are at least four new species, two of which, the Triloculina referred to in the pr eceding paragraph, and *Discorbis* sp. nov., are confined to the shore sands and Recent dunes. Another, *Calcarina* sp. nov., ranges from the shore sands to the 10 to 24 foot raised beach at Point Peron ; this species is common in shore sands from the coast around Fremantle. The fourth species is the *Anomalina* which occurs in the Late Pleistocene of Trigg Island.

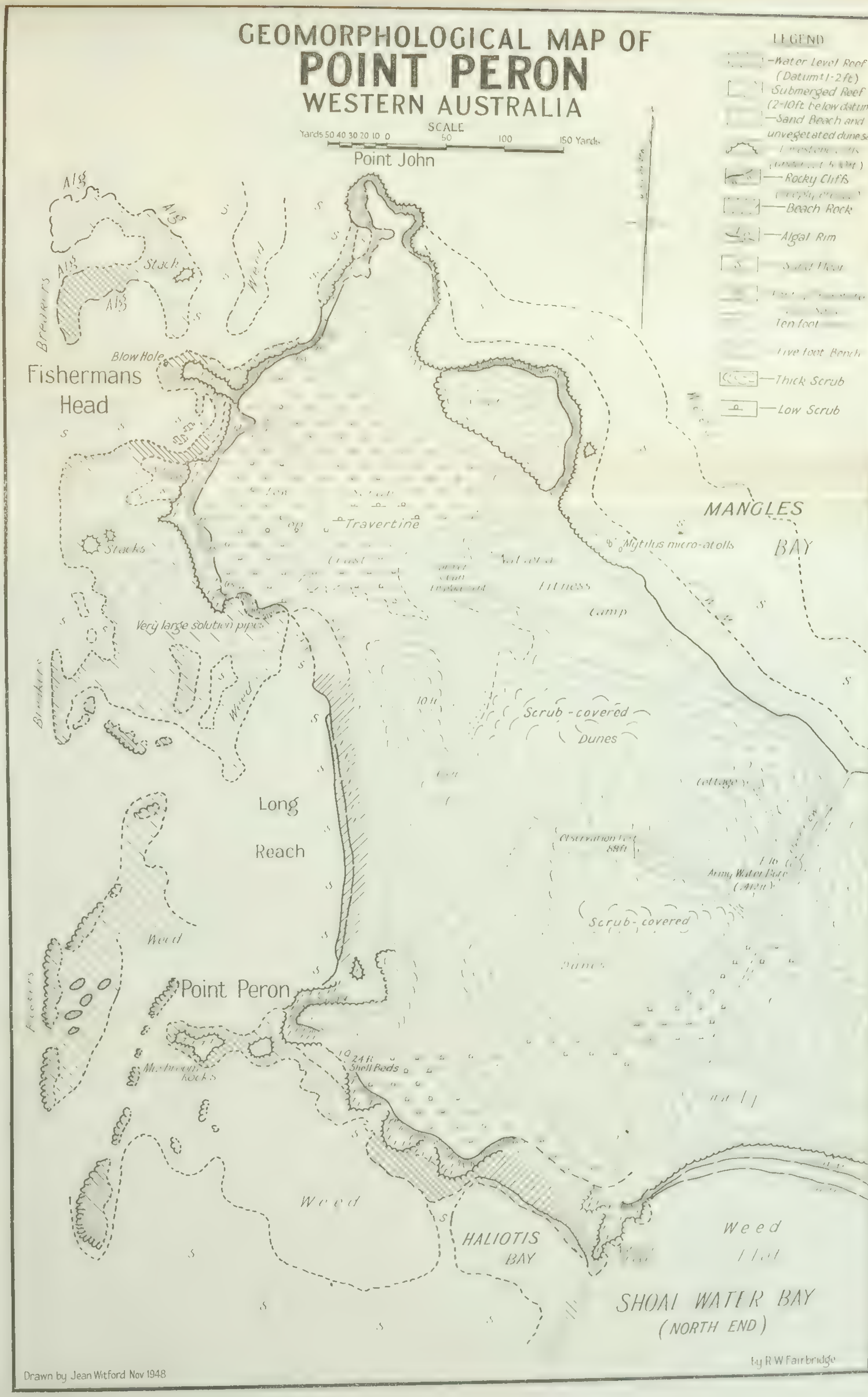


Plate I.

Geomorphological map of Point Peron, W.A. Based on air photographs and ground survey.

4.—THE WESTERN AUSTRALIAN VARIETIES OF *Eucalyptus oleosa* F. Muell. ex. Miq. AND THEIR ESSENTIAL OILS.

By

C. A. GARDNER AND E. M. WATSON.

Read 8th June, 1948.

I.—INTRODUCTION.

Amongst the species of *Eucalyptus* which prove difficult from the systematic viewpoint, two are outstanding because of their variability and the forms they assume. These are *Eucalyptus dumosa* A. Cunn., and *Eucalyptus oleosa* F. Muell. Both of them are species which have a wide geographical range, inhabiting many soil types and different environments. Recent workers on the genus have tended towards a narrower definition of species within the genus, and as a result considerable confusion has arison, not only because of the variability of these species, but also because they have been established on characters which are not constant. In the case of *Eucalyptus oleosa* F. Muell., too much reliance has been placed on the shape and comparative size of the operculum and fruit, and these can be demonstrated to be extremely variable ; furthermore, some of these recently described "species" have been established on incomplete material, and finally, the question of what *Eucalyptus oleosa* really is, *i.e.*, by reference to the specimens first described, has been largely overlooked.

It was a common practice amongst the botanists of the last century, to describe a new species from two or more separate collections without designating a type, thus sometimes such composite descriptions embraced more than one species ; thus, in *Eucalyptus oleosa* we have a description based upon two separated localities, with no type specimen indicated, and no chosen lectotype.

The purpose of the systematic portion of this paper is an attempt to elucidate this question insofar as it concerns *Eucalyptus oleosa*, and to segregate the various forms found in Western Australia, with reference to the original description.

II.—HISTORY.

Eucalyptus oleosa F. Muell. ex Miq., was described in Nederlandsch kruidkundig archief iv. 128 (1856).

Following is the original description, in which I have substituted (for convenience, and for purposes of comparison) the metric system of measurement in place of the "inches" and "lines" employed in the original.

10, Eucalyptus oleosa *F. Muell. E. perforata* Behr, Herb. parte. *Eucalyptus strictae* Sieb. affinis.

Marble Range (*Wilhelmi*) ; Murray Scrub (*Behr*).

Frutex, ramulis angulatis, foliis anguste lanceolatis vel sublinearibus in acumen uncinatum tenue vulgo saphacelatum excurrentibus, basi attenuatis, ut plurimum inaequilateralis, coriaceis crebo pellucido-glandulosis, venis subobtectis erecto-patulis, umbellis axillaribus,

> 4–10-flóris pedunculo angulato sustentis, floribus breviter pedicellatis vel subsessilibus, operculo conico-hemisphaerico obtusiusculo tubum obconico-turbinatum subaequante.
>
> "Frutex hominem altus, coma laetissime viridi nitente" (*Behr*). Ramuli angulati albido-pallidi vel juniores saturate fusculi. Petioli 6–8 mm. longi in sicco luteoli. Folia 4–6.3 cm., vulgo circiter 5 cm. longa, 4–6 mm. lata, recta vel obliqua. Pedunculi 4 mm. vix aequantes. Calyx 3 mm. aequans, haud raro operculo sublongior, pallidus. Filamenta pallida.

There are two interesting points regarding the above description ; in the first place it is based upon two separate collections, and in the second place it was described by Mueller ex Miquel in a European publication. It is suggested that Miquel who communicated the paper, may have been in part responsible for the description, since the Latin does not conform with Mueller's style (at least for his later descriptions). If this should prove to be the case, then the type sheets (or original specimens) were probably retained by Miquel, and are in some European Herbarium, probably that of Utrecht. This point is referred to later.

Mueller subsequently described *E. oleosa* (1860), again from mixed material, and giving *E. leptophylla* F. Muell. as a synonym, so that this description can be dismissed as being entirely unsatisfactory.

Diels (1905) makes no contribution in his references to this species, beyond giving the geographical range in Western Australia, but confuses the var. *glauca* with the var. *longicornis*. He makes notes on the affinities of the species.

It was next described by Maiden (1912), who, while drawing attention to the fact that the earlier descriptions were from mixed material, further complicates matters by including other forms, and speaks of the typical form without any reference to the original specimens, which he did not see. In discussing the range of *E. oleosa* he gives a number of Western Australian localities, extending from the Murchison River to Ravensthorpe, all belonging to his "typical form," including one which he saw at Pindar, and which he describes as "a small tree with a rough dark flaky bark and smooth limbs, dark brown timber which is darker than is usually the case with *E. oleosa*." Other references to *Eucalyptus oleosa* are found at intervals in Maiden's work, several varieties being described, all of which with the single exception of the var. *angustifolia* being subsequently raised to specific rank. These "species" are dealt with under the varieties proposed in this paper. *E. oleosa* var. *angustifolia* Maiden, was published without a description, but references were made to illustrations, amongst which two forms may be distinguished. It was Blakely (1934) who described it as follows :—

> Small shrubs 1–2 metres high, with light glossy, green narrow-lanceolate leaves 5-7 cm. long, and 6–9 mm. broad. Buds cylindroid, 5 mm. long. Operculum sub-obtuse to obtuse. Fruit pedicellate, globular-pyriform, 4–5 by 4 mm., thick, with frail subulate protruding valves. The type is "Dublin Scrub, Pinnaroo, *J. M. Black*."

J. M. Black (1926), in discussing the forms of *Eucalyptus oleosa*, states :— "A form with very narrow glossy leaves, only 7–10 mm. broad, growing in the scrub near Pinnaroo, has a blunt conical cap, and 3-celled globular fruit, 4 mm. long, with a rather broad rim. It is only 1–2 metres high, and is locally called Green Mallee."

These two descriptions should be compared with the original description. I can detect no essential points of difference between them, and conclude that the variety *angustifolia* Maiden, is identical with the original description, and would conform with the specimens from the Murray Scrub collected by Behr.

Burbidge (1947) makes the next contribution. A search in the Melbourne Herbarium having failed to reveal the original specimens, or specimens that could be identified as the original, a request was sent to the Utrecht Herbarium, and a photograph and some fragments were received. Burbidge states "It is mixed *E. uncinata* Turcz. (buds and flowers), and *E. oleosa* F. Muell. (immature fruits). The latter, which is regarded as the true type, was, according to the Melbourne authorities, collected from the Murray Mallee. When inquiries concerning the type was first made, it was hoped that the specimen would show the shape of the operculum, since this feature is variable, and has been the basis of differentiation in several varieties. Unfortunately this is still unsettled." Unfortunately Miss Burbidge makes no reference to the leaves of the Murray Mallee specimens, nor to the collector.

According to Burbidge, Blakely considered raising the var. *angustifolia* to specific rank under the name *E. lamprophylla*, but apparently he included in this all forms with an obtuse sub-cylindrical operculum, irrespective of other differences. This was not accomplished, but had it been done, tree forms with broadly lanceolate lustrous leaves from the Coolgardie district would have been included, which must be very different from the Pinnaroo Mallee. Burbidge described *E. oleosa sensu stricto*, as a mallee or small tree with a conical operculum longer than the cupular or semi-globular calyx-tube, the leaves narrow-lanceolate, *usually* glossy, 5–10 cm. long, and 1–2 cm. broad. The figures referred to this closely resemble the buds and fruits of the var. *longicornis* forma *gracilis*.

It will be seen from the above that apart from the original description, and the type material, to which reference has been made by only one subsequent writer, considerable confusion has accumulated round the species. The original material has not been redescribed, and as a result of speculation as to what *Eucalyptus oleosa* is, some variety, or varieties have come to be regarded as the typical form, while the only description which can be regarded as being comparable with the original description of the species, is that of the var. *angustifolia*.

III.—SYSTEMATIC.

Six distinct forms of *Eucalyptus oleosa* can be recognised in Western Australia. None of them agree with the original description of the species, and thus all of them are varieties. Of these, three have been described as species by Maiden—*Eucalyptus transcontinentalis* (var. *glauca* Maiden); *E. Kochii* (var. *Kochii* C. A. Gardn.), and *E. Grasbyi* (var. *longicornis* F. Muell. forma *gracilis*.)

The following key will serve to distinguish these varieties :—

A. Leaves lustrous, or with a matt surface, not glaucous, drying greenish, yellowish or pale ; operculum not attenuated-rostrate.

B. Leaves spreading, with evident secondary nervation, and conspicuous dark oil-cavities (at least when dry) ; calyx-tube at anthesis abruptly contracted into the slender pedicel.

C. Leaves dark green and lustrous ; pedicels longer than the calyx-tube.

D. Operculum conical, acute, from as long as, to twice or more than twice the length of the calyx-tube.

α. var. **longicornis** F. Muell.

D. Operculum hemispherical-cylindrical, very obtuse, sometimes apiculate-umbonate, often ± wrinkled (at least when dry) about as long as the calyx-tube and usually different from it in colour.

β. var. **obtusa** C.A. Gardn.

C. Leaves sublustrous, drying yellowish-green ; pedicels shorter than the calyx-tube at anthesis ; operculum obtusely conical to ovoid. subequal to the calyx-tube.

γ. var. **borealis** C.A. Gardn.

B. Leaves, erect, rather rigid, the secondary nervation not evident in the mature leaf, the midrib showing as a narrow groove, the lamina never lustrous, drying pale ; oil-cavities never, or rarely seen on the mature leaf ; calyx-tube tapering into the angular pedicel.

C. Leaves narrow-lanceolate to linear-lanceolate ; mature buds with a conical rather acute operculum as long as, or longer than the calyx-tube and paler in colour.

δ. var. **Kochii** C.A. Gardn.

C. Leaves narrow-oblong, rarely oblong ; operculum hemispherical, very obtuse, rarely ovoid-hemispherical, shorter than the calyx-tube ; buds often large and robust ; pedicels ± ancipitous, the angles (in the bud at anthesis) usually extending along the calyx-tube.

ϵ var. **plenissima** C.A. Gardn.

A. Leaves glaucous, broadly falcate-lanceolate ; secondary nervation rather distinct ; operculum ovoid, attenuated into a slender (rarely short) beak ; buds and fruits usu. glaucous.

ζ var. **glauca** Maiden.

α. var. **longicornis** F. Muell. Fragm. xi. 14 (1878)

The „ Morrel." Typically a fairly large tree, attaining a height of 25 metres. Differs from the typical form in its size, broader dark-green leaves, and acutely conical operculum, which varies from more than twice the length

of the calyx-tube, to about an equal length. Its habitat extends from Carnamah in the north, thence its western boundary extends through Moora and Northam to Wagin, Katanning and Broome Hill to Gnowangerup. Eastwards it extends to beyond Southern Cross.

Eucalyptus Grasbyi Maiden and Blakely, described from a specimen collected at Lake Barlee by Fitzgerald Fraser, is a smaller, narrow-leaved and smaller flowered form of this variety (forma *gracilis*), and approaches to, if not the same as what Burbidge described as *E. oleosa* F. Muell. *sensu stricto*. The specimens are not in fruit, but I cannot separate it from the var. *longicornis* in anything but the size of the leaves and the inflorescence.

β. var. **obtusa** *C. A. Gardn.* var. nov.

Arbor elata ; foliis lanceolatis, nitentibus ; pedunculis tenuibus ; receptaculo cupulo quam operculum cylindrico-hemispherico subaequante, cetera typi.

Erect tree 7–13 metres tall, with widely spreading branches ; trunk to five metres tall and 45 cm. diameter, the bark, to a height of 3–4 metres persistent, close, pale grey, more tessellated than in the var. *longicornis*, and never very thick, that of the upper portions smooth and of a rich brown colour streaked with grey and decorticating in long ribbon-like strips often persisting as a rough collar at the summit of the rough-barked portion ; timber deep red and very hard. Branchlets terete or slightly angular. Leaves on petioles up to 1 cm. long ; lamina lustrous, lanceolate, acute or acuminate and uncinate, scarcely oblique at the base, and tapering into the petiole, copiously dark-dotted with oil-cavities, the midrib but slightly impressed on one surface, and raised on the other surface, the secondary nervation distinct, spreading widely and anastomosing with the intramarginal nerve which is remote from the margin. Peduncles axillary and lateral, terete, rather slender, 1 cm. long, 3–7-flowered, expanded at the top ; pedicels terete, 3–5 mm. long ; buds (at anthesis) ± oblong in outline, 7–8 mm. long ; calyx-tube hemispherical-cupular, 4 mm. long, abruptly contracted into the pedicel, smooth ; operculum darker in colour than the calyx-tube, cylindrical-hemispherical or cylindrical-ovoid, smooth, 4–4.5 mm. long and broad ; filaments pale. Fruit globular-hemispherical, 6 mm. long and broad.

Coolgardie district : Montana Hill, Coolgardie, in red stony soil, fl. m. October, *Gardner* 1839 (type) ; Widgiemooltha, in red loamy subsaline soil, *Gardner* 1754 ; Bremer Range, *Gardner* sine no.

Differs from the typical form of *E. oleosa* in being a comparatively tall tree with broader leaves, and very obtuse opercula.

γ. var. **borealis** *C. A. Gardn.* var. nov.

Arbor erecta ; foliis falcato-lanceolatis, subnitentibus ; punctatis, venis lateralibus pennato-patentibus, vena intramarginali a margine remota ; tubo calycis campanulato, ad basin obtusissimo ; operculo ovoideo-hemisphereico, cetera typi.

Tree 10–17 metres tall, trunk up to one metre or more in diameter ; bark of the trunk and lower part of the branches dark grey, persistent, fibrous-lamellar, thick, ± spirally longitudinally fissured, the fissures narrow and deep, upwards thinly lamellar and almost ribbony, the upper parts of the branches and branchlets terete or angular, smooth, spreading. Leaves

alternate, spreading, lanceolate-falcate, green, sub-lustrous but not shining, drying yellowish-green ; petioles slender, up to 1 cm. long ; lamina relatively thin, scarcely oblique at the base, tapering into the petiole, abruptly acuminate and uncinate, mostly 6–7 cm. long and 10–15 mm. broad, copiously punctate with dark oil-dots, the midrib scarcely impressed, the lateral nerves distinct, few, spreading, anastomosing with the intramarginal nerve which is removed from the marginal area. Umbels chiefly lateral ; peduncles angular, 5 mm. long, rather slender, bearing mostly 5–7 flowers ; pedicels 2–3 mm. long, terete or slightly angular, slender ; buds at anthesis 6–7 mm. long. Calyx-tube campanulate, 3.5 mm. long, abruptly contracted into the pedicel, smooth and shining ; operculum ovoid-obtuse, or very rarely ovoid-conical, 2.5–3 mm. long, smooth, usually paler in colour than the calyx-tube ; filaments white ; anthers as in the typical form ; style 3 mm. long. Fruit globular-ovoid, 6–7 mm. long, and as much in diameter in the lower half, 3.5 mm. broad at the summit, the orifice 3 mm. wide ; valves subulate, slender, exserted.

Habitat :—6–8 miles eastwards from Canna, on loamy reddish forest soil on flats, fl. m. Novem.-Jan., *Watson and Gardner* (Type), *Gardner* 8516, *L. R. Lovell* 5, 7, 9 and 10 ; eastwards from Gutha, on the Yalgoo Road, *Lovell* ; Gutha, *Gardner* ; 6 miles eastwards from Pindar, *Lovell and Gardner*.

Distinguished by the broad sublustrous thin spreading or pendulous leaves, non costate campanulate calyx, by the habit and dark-coloured bark, and the dark-punctate rather prominently nerved leaves. Differs from the var. *obtusa* in the paler and broader leaves, and the shape of the calyx and operculum.

From the vars. *Kochii* and *plenissima* it differs in the shape and texture of the leaves, as well as in their colour, in the campanulate calyx abruptly contracted into the pedicel, and generally in the shape of the operculum, as well as in the venation of the leaves, and their copious dark oil-dots.

δ. var. **Kochii** *C. A. Gardn.* var. nov.

Foliis lineari-lanceolatis ; operculo conico cupulae aequali ; frutex vel arbor ; foliis opacis, acuminatis, epunctatis, nervo media vix prominulo, caeterum avenia.

A tree attaining a height of 12 metres, or a mallee of 2–5 metres, the tree with a grey fibrous ± latticed rough persistent bark on the trunk and lower portions of the branches, the upper parts and branchlets smooth and brownish-pink in colour, the branchlets pale or reddish, terete or slightly angular, the trunk up to 9 inches in diameter. Young leaves alternate lanceolate to ovate-lanceolate, glaucous-pruinose, subsessile, tapering at the base, the apex shortly acute and ± ustulate-mucronate, the midrib prominent (at least underneath), the intramarginal nerve remote from the edge of the leaf, the lamina 2–4 cm. long, 8–10 mm. broad.

Normal leaves alternate, oblong-linear to linear-lanceolate or almost linear, erect, the petiole yellowish, twisted, broad at the base, tapering upwards into the lamina, the lamina straight or slightly falcate, acute or acuminate, continued into a slender, usually uncinate point, usually 7–8 cm. long, 5–8 mm. broad, sublustrous or subglaucous, flat, the midrib narrow but fairly prominent and ± depressed on both surfaces, the lateral nerves not numerous, not evident, at an angle of about 45 degrees to the midrib, the intramarginal nerve removed from the margin, the marginal area thick, translucent, nerve-like, usually one margin reddish-coloured, the other pale.

Umbels axillary and lateral (through leaf-suppression), erect, solitary or rarely paired : peduncles stout, terete or slightly compressed, much thickened upwards, 7–8 mm. long, bearing usually 6–10 flowers ; when young, with an expanded disc-like margin, when paired usually one long and one short ; buds at first oblong in outline, later fusiform. Calyx-tube turbinate-obconical, tapering into the terete (later 2-angled) pedicel of 2–3 mm., the calyx 3.5–4 mm. long, pale when in blossom, 3.5 mm. diameter at the summit, sub-2-costate. Operculum conical, 4–5 mm. long, smooth, the commissural margin narrowly constricted, pale-coloured, acute, the apex straight or slightly curved, with a gland-like point. Stamens numerous, the filaments all fertile, pale yellow or almost white, twice as long as the calyx-tube ; anthers erect, subquadrate, basally attached, obtuse, opening in short broad lateral ± oval thecae. Fruit ovoid-truncate, smooth or becoming wrinkled when dry, somewhat abruptly tapering into the pedicel which is 2.5 mm. long, 6–7 mm. long, 5–6 mm. broad in the lower part, the summit 4 mm. broad ; rim narrow, the orifice 3 mm. broad ; disc vertical, 2 mm. long, lining the orifice ; valves subulate, exserted, the tips breaking off below the orifice with age ; seeds orbicular-obovate, compressed and sublenticular with acute angles, dark brown and smooth. Fl. m. January.—*E. Kochii* Maiden et Blakely.

Habitat :—10 miles eastwards from Pindar, *Gardner* 8518 ; eastwards from Perenjori, on the Damperwah Road, *L. R. Lovell* 15 ; 5 miles E. from Dalwallinu, a mallee in sandy grey loamy soil, with *E. leptophylla* and *Melaleuca uncinata*, *Gardner* 8509 ; Rabbit-proof Fence, 25 m. E. from Dalwallinu, *Gardner* 8519, 8519a, 8524 (Type), 8525 ; Watheroo Rabbit Fence (probably the Dalwallinu gate locality previously quoted), *Max Koch* ; 10 miles eastwards from Pithara, on the Kalannie Road, in reddish loamy soil with *Acacia acuminata* and *Melaleuca uncinata*, *Gardner* 8521 ; Rabbit-proof Fence, West from Kalannie, in wodjil country, *Gardner* 8535 ; 4 miles E. from Bunketch, a mallee in sandy soil, *Gardner* 8527 ; Rabbit-proof Fence, E. from Ballidu, *Gardner* 8538 ; between Kondut and Ballidu, *Gardner* 8539.

ε. var. **plenissima** *C. A. Gardn.* var. nov.

Frutex, vel arbor parva ; foliis erectis lineari-oblongis, epunctatis, concoloribus, nec nitenti-viridibus neque glaucis ; calyce turbinato, basin versus attenuato ; operculo hemisphaerico, obtuso, cetera typi.

A bushy mallee 3–6 metres tall, and densely branched with erect-spreading densely foliaged branches, the lower parts with a dark or pale grey ± spirally fibrous bark, the upper parts with a smooth reddish-grey bark, or a tree 7-10 metres tall, with spreading branches, the trunk up to 40 cm. diameter, the bark of the trunk and branches pale or dark grey, fibrous and ± spirally fissured, the fissures narrow and rather deep, that of the branches reddish-grey and decorticating in long plates. Leaves erect, the petiole up to 1 cm. long, the lamina oblong to linear-oblong, acute, never acuminate, uncinate, rather thick, drying pale, green in colour with a matt surface, without visible oil-glands when mature, up to 10 cm. long, rarely exceeding 1 cm. in breadth ; more rarely elliptical-oblong and 1–2 cm. broad, the upper margin usually reddish, the lower pale ; midrib impressed on both surfaces, the secondary nervation not evident in the mature leaf, the intramarginal nerve submarginal. Umbels axillary, mostly 6–8-flowered, peduncles stout, terete or angular, 5–8 mm. long, expanded at the top ; buds obovoid-pyriform to obovoid-oblong, 7–8 mm. long ; pedicels 2–4 mm. long. Calyx-tube campanulate-turbinate, 4–6 mm.

long, gradually tapering into the angular ancipitous pedicel, the angles of which usually extend for a greater or lesser distance up the calyx-tube, the tube otherwise smooth ; operculum depressed-hemispherical to ovoid-hemispherical, up to 5 mm. broad, very obtuse or sometimes apiculate-umbonate, smooth, shorter than the calyx-tube ; filaments, anthers and style as in the typical form. Fruit ovoid to urceolate-ovoid or globular-ovoid, on very short pedicels.

Habitat :—Rabbit-proof Fence, 1 mile South of the Pithara-Kalannie Road, *Gardner* 8520 ; Rabbit-proof Fence westwards from Kalannie, *Gardner* 8536 ; Rabbit-proof Fence eastwards from Ballidu, *Gardner* 8538a ; near Kalannie, *Gardner* 8526 ; 4 miles eastwards from Mollerin, *Gardner* 1830 ; between Beacon and Wialki, in sandy soil, *Gardner* 8532 (Type) ; near Nembudding, 8542, Yorkrakine, 8543, North from Mukinbudin, and near Campion, *Gardner*.

var. **glauca** Maiden in *Journ. W.A. Nat. Hist. Soc.* iii. 171 (1911)

(*E. transcontinentalis* Maiden ; *E. socialis* F. Muell.)

This tree is the " Redwood " of the Coolgardie district. It is described by Maiden as a " White Gum " with a blotched bark, and more or less shortly ribbony-flaky on the trunk, with a little roughness at the base. Examples with a perfectly smooth bark throughout are not uncommon, the bark decorticating in long ribbon-like strips. On the other hand " half-barks " in which the greater part of the trunk is rough-barked, and specimens with all but the upper branches rough-barked, are not uncommon. The inflorescence is usually distinctly glaucous, and sometimes the fruits also, but in some specimens this glaucous " bloom " is wanting. The leaves, however, are never lustrous, varying from a distinctly glaucous, to a subglaucous green, and the buds always have a rostrate operculum, typically with a long slender beak, but the beak sometimes short and rather thick. It approaches in some forms very closely to *E. Flocktoniae*, and is somewhat difficult to separate from the latter. *E. Flocktoniae* however, as far as I am acquainted with the species, has a distinctly lustrous dark green foliage, broadly expanded base of the operculum, and distinctly urceolate fruits. Its coppice leaves also appear to be distinct.

IV.—THE SURVEY.

In November, 1944, while examining some country to the east of Canna, the first specimen of the var. *borealis* was encountered on an abandoned farm, and, upon examination proved interesting because of the yield and quality of the oil obtained from its leaves. The specimens were determined as *Eucalyptus Kochii* Maiden et Blakely, and the result of the chemical investigations published by Watson (1948). Further investigations instituted by a local firm interested in the subject traced this tree northwards to the Pindar district, and some distance to the east of both localities, with many intermediate records. Further south, in the vicinity of Dalwallinu another form was discovered, extending from the immediate east of Dalwallinu, to the Rabbit-proof Fence, and some little distance to the south, and this proved to be identical with the specimens collected by Max Koch in September, 1904, and named *Eucalyptus Kochii* by Maiden and Blakely. A third, and still more productive form was discovered near Kalannie, a field distillation of fresh twigs giving an oil yield of 3.45 per cent. This is the var. *plenissima*, which was subsequently found to extend from the Rabbit-proof fence near

Pithara southwards to near Ballidu and Kondut, and eastwards to beyond Wialki, Mukinbudin and Campion, and southwards to Korrelocking, Nembudding and Yorkrakine, and has been seen again at Hine's Hill.

The matter was taken up by the Drug Panel of the Department of Industrial Development, and a survey was undertaken of this third variety (var. *plenissima*) and of the var. *Kochii*. This work was commenced in February, 1947, when the above range was outlined, and twenty sites, each representing either distinct forms, or distinct environments, were selected for the two varieties. The var. *plenissima* has the wider range, and the greater number of sites represented this variety. The number was gradually reduced during subsequent collections. Material was collected at three-monthly intervals, in each case from the same tree or mallee, or where this was not possible, for an adjacent plant of similar type. Some were adult mallees and trees, others were smaller more vigorous mallee forms which represented regrowth of approximately 8–10 years, on land which had been previously cultivated for farms, and later abandoned. Others were regrowth taken from young natural regrowth of a metre or less in height ; and with these the material in all but one instance (K4), was collected mainly from growth made during the intervals between the collections.

The collecting periods were 4–6th February, 1947 ; 29th April to 1st May, 1947 ; 22nd to 24th July, 1947 ; 5th to 7th November, 1947 : 27th to 29th January, 1948, and for the var. *plenissima* 13th to 15th April, 1948. Sites K19 and K20, were established near Nembudding in May, 1947, and the first collections made at that time.

After ten sites had been discarded, the following sites were chosen, and quarterly collections made at the periods stated above :—

var. *Kochii*.—Site K2. Dalwallinu Fence gate. Tree in loamy depression.

Site K3. same site. Mallee (adult form).

var. *plenissima*.—Site K4. Rabbit-proof Fence, 4 miles south from the Dalwallinu gate ; regrowth from mallee, in clay soil.

Site K5. Site of K4 ; mallee 18 feet tall.

Site K7. 1 mile N.W. from Kalannie ; mallee 10–15 ft. tall, in open places on previously cleared land, in sandy loam.

Site K7*a*. Mallee on the K7 site, cut down on the 4th February, 1947 ; made regrowth as follows :—

29th April, 27 ins. tall ; 22nd July, 28 ins. tall ; 5th November, 30 ins. tall ; 13th April, 35 ins. tall—the bark much damaged by rabbits.

Site K10. 7 miles E. from Kulja, on roadside. Mallee 12–15 ft. tall, in red loamy soil on flat.

Site K11. 7 miles E. from Kulja, on roadside ; regrowth 2–3 ft. tall ; leaves glaucous.

Site K18. Yorkrakine. Mallee 4–8 ft. tall, in sandy soil in depression.

Site K19. 1 mile West from Nembudding Siding ; mallee regrowth 1–2 ft. tall, in sandy soil ; leaves mostly glaucous.

Site K20. 1 mile West from Nembudding, in sandy soil ; mallee 6–10 ft. tall.

The var. *Kochii* formerly covered wide tracts in the Dalwallinu district, and the same is true for the var. *plenissima*, at least in the Kalannie district. The soils these inhabit are regarded as good agricultural land, and the main evidence of their former extent is to be gained from the prevalence of these plants along the roadsides and on fence lines bordering cultivated areas.

The var. *Kochii.* in the main, inhabits a clay loamy soil, especially in the Dalwallinu country ; further south, *e.g.*, Bunketch and towards Ballidu, it is found in sandy loamy, or sandy soil. Its associated plants in the typical environment are *Acacia acuminata* Benth. (shrubby form) ; *Melaleuca uncinata* R.Br., *Acacia Graffiana* F. Muell. and *Eremophila Drummondii* F. Muell. and usually *Grevillea Huegelii* Meissn. The tree form and the mallee form are usually associated, and wherever this variety has been found, most of the country has been cleared for agricultural purposes, and much of it subsequently abandoned. Unlike many mallees, the subterranean stock is easily broken up or dislodged by the plough, so that the regeneration in cultivated land is surprisingly low. The same remark applies to the var. *plenissima* which is comparatively rare on country previously denuded of vegetation and subject to the plough.

The var. *plenissima* enjoys a wider range, and inhabits a greater variation in soil types than does the var. *Kochii.* Like the var. *Kochii* it is most frequently associated with *Acacia acuminata* Benth. and *Melaleuca uncinata* R.Br., but it is also found in sand-plain country, and on heavy forest soil associated with *Eucalyptus redunca* and with *E. foecunda.* In the eastern areas of its known distribution it is found as a small stunted tree with tortuous branches and coarse foliage in red sand associated with *Callitris glauca.* It is remarkable amongst the dry country mallees for the density of its foliage and its rich branching. Until the plants attain a height of about six or eight feet they are densely branched from the base, forming dense globular shrubs ; as the upper branches develop, the lower branches die, and in mallees in the transitional stage, there is usually a mass of closely growing dead branches around the stock. The branchlets of the young mallees are weak and spreading or drooping, and commonly a deep red in colour ; the flowering and fruiting branches and branchlets, and those of the upper parts of the mallees, and the trees also, are pale in colour. The density of the branches and the foliage in the younger mallees makes them readily recognisable among their congeners, and prove the most outstanding features of the plant.

NOTE.

Since the above was written, I have received from Miss N. T. Burbidge, an excellent photographic representation of the sheet in the Utrecht Herbarium, which is regarded as the type. This photograph clears up a few points that were previously doubtful. It shows three twigs : the largest (upper right hand side) is indubitably *E. uncinata* Turcz., showing leaves and flowers ; below this is a fragment showing small leaves and flower-buds, also *E. uncinata* Turcz. On the left-hand side is *E. oleosa* showing super-floral leaves, and lateral umbels with advanced flowers ; there are neither buds nor fruits The label is as follows :—

"Eucalyptus oleosa F. Mull.
Marble range (Wilhelmi)
Murray Scrub
Novo Holl. austr.
F. Muller."

It will be noticed that Behr's name is not included.

Regarding the specimen of *Eucalyptus oleosa* the following features are well illustrated by the photograph : the leaf lamina varies from 4.5–5.6 cm. in length, and about 9–10 mm. in breadth. The leaves are copiously dark-punctate with prominent oil-cavities, the midrib is conspicuous, and the secondary nervation evident ; the intramarginal nerve is well removed from the margin of the leaf. I would describe the shape of the leaf as varying from lanceolate to oblong-lanceolate, attenuate and slightly oblique at the base, the apex shortly acuminate and ustulate-uncinate. The peduncles are distinctly thickened upwards ; the umbels are up to 8-flowered ; the immature fruits hemispherical-cupular (probably becoming globular-hemispherical at maturity), 4–5 mm. in diameter, and about as much in length. The disc would probably be rather prominent. On two inflorescences the peduncle appears to show a pale decorticating cortex ; the immature fruits are abruptly contracted into rather slender pedicels which vary in length from slightly shorter than, to longer than the calyx-tube.

It is evident that the original description was drawn up from the specimens of both species (*E. uncinata* and *E. oleosa*). The breadth of the leaf, the number of flowers in the umbel, " shortly pedicellate or subsessile," and the opercula, are all taken from Wilhelmi's specimens (represented in the Melbourne Herbarium by specimens from the Marble Range, north of Port Lincoln). All that we can be certain about regarding *E. oleosa* in the original description, is the statement attributed to Behr " Shrub the height of a man ; leaves a very pleasing shining green." There is, however, nothing on the Utrecht sheet to indicate that the specimen is Behr's ; the label suggests that Mueller collected it himself in Southern Australia.

There appears, therefore, some doubt as to the propriety of regarding the species as valid, but, if *Eucalyptus oleosa* is to be retained, then the inadequate material on the Utrecht sheet is apparently the type (*i.e.*, that portion of the sheet which represents *E. oleosa*, and not *E. uncinata*), and although Behr is not shown to be the collector, his remarks which were included in the original description, should be taken into account, and these, as far as the descriptions indicate, apply to, and only to, the Green Mallee of the Pinnaroo district. Apart from this, the original description, based upon two species, applies more to *E. uncinata* Turcz., than to *E. oleosa* F. Muell.

V.—THE ESSENTIAL OILS.

Volatile oils from three Western Australian varieties of *E. oleosa* F. Muell. have already been described. The oil of variety *longicornis* was described by Baker and Smith (1920) who had distilled it from material collected from trees cultivated in the Melbourne Botanical Gardens. The oil of variety *obtusa*, the so-called giant black mallee of the south-eastern goldfields, was the subject of a paper by Marshall and Watson (1936–37). The oils from three samples of *E. Kochii* Maiden et Blakely, which are now recognised as specimens of *E. oleosa* var. *borealis*, were dealt with in a brief preliminary note by Watson (1948).

The oils described in the present paper are from the varieties *borealis*, *Kochii* and *plenissima*.

Yield.

The oils were steam distilled from thoroughly air dried branchlets and the percentage yields were calculated from the air dried weight. A series of tests carried out on material collected at the end of April and the beginning

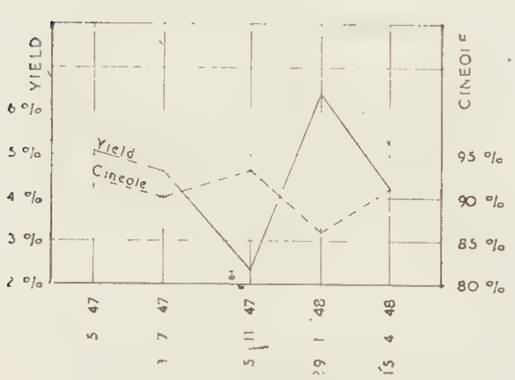
of May, 1947, showed that the loss of weight on drying the varieties *Kochii* and *plenissima* varied from 38 to 42 per cent., averaging a little over 40 per cent. The results of the oil distillations are summarised in Table 1.

TABLE 1.

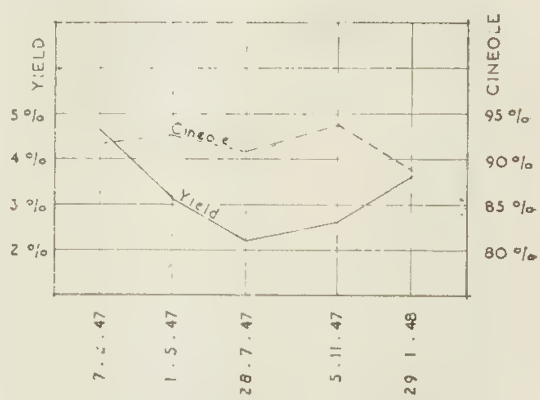
Variety.	Number of specimens.	Time Collected.	Percentage yield.	
			Range.	Average.
borealis	13	End of November to January	2.1–4.7	3.0
Kochii	23	Three monthly intervals	2.3–5.5	3.5
plenissima	49	Three monthly intervals	2.2–8.6	4.2

The yield from var. *plenissima* is significantly higher than those from the other two varieties.

There is in general a marked seasonal variation in yield, a defined "flush" period occurring in the first half of the summer, probably reaching a maximum in January. This is shown clearly by specimen K20 (var. *plenissima*), a mature mallee occurring 6 miles east of Korrelocking, the oil yield from which increased from 2.5 per cent. on 5th November, 1947, to 6.4 per cent. on 29th January, 1948, and then fell to 4.2 per cent. by 15th April, 1948 (text fig. 1). The summer maximum is not always as well defined as this. For example, K18 (var. *plenissima*) from Yorkrakine showed a summer maximum of 4.7 per cent. and a winter minimum of 2.2 per cent., with a much slower rate of change (text fig. 2).

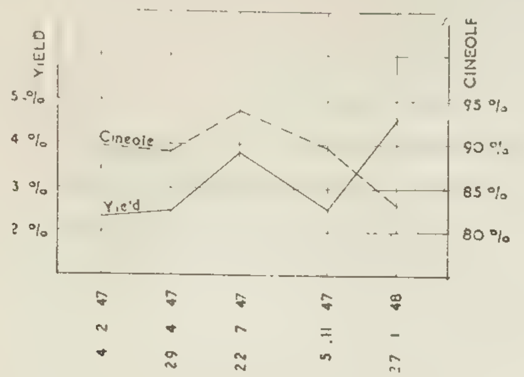


Text Fig. 1, K20, Korrelocking.
Var. *plenissima*.



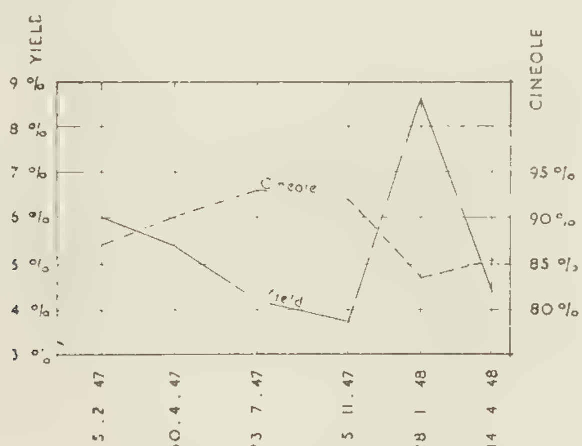
Text Fig. 2, K18, Yorkrakine.
Var. *plenissima*.

Two specimens of var. *Kochii* (K2 and K3), examined regularly from 4th February, 1947, until 27th January, 1948, showed, in addition to the summer maximum, a second peak in mid-winter (text fig. 3). Examination of the weather records for the locality gave no indication of any difference in weather conditions compared with those at other sites likely to account for the production of a winter peak. Indeed, specimen K4 (var. *plenissima*), which was collected only 2 miles from K3, showed the typical winter minimum observed with all other specimens of var. *plenissima*.



Text Fig. 3, K2, Dalwallinu.
Var. *Kochii.*

The yield obtained from regrowth, following the cutting or burning of mallees to the ground, is invariably higher than that obtained from mature mallees or trees, and the " flush " period is very clearly defined. Thus K11 (regrowth, var. *plenissima*) (text fig. 4), gave a minimum yield of 3.7 per cent. on 5th November, 1947, rising to a maximum of 8.6 per cent. on 28th January, 1948, and falling to 4.3 per cent. by 14th April. Similarly K19 (regrowth adjacent to K20) showed a minimum of 3.6 per cent. on 5th November, 1947, rising to a maximum of 7.2 per cent. by 29th January, 1948.



Text Fig. 4, K11, Kulja.
Var. *plenissima* (Regrowth).

*Physical Properties.**

Physically there is little difference between the oils of the three varieties. Specific gravities varied from 0.919 to 0.927, refractive indices from 1.4590 to 1.4630 and specific rotations from $+0.45°$ to $+3.80°$. A reasonably close agreement was shown between specific gravity and cineole content, a high specific gravity almost invariably indicating a high cineole content. The oils of lower cineole content were always those of higher refractive index and higher optical rotation.

Chemical Properties.

Chemically, principal interest has centred in the cineole contents of the oils. Work on the minor constituents is in hand. The variety *borealis* has only been examined during the summer months from the end of November

* Physical properties are given at 20°C.

to the end of January. Of the 13 specimens examined, two showed cineole contents of less than 80 per cent. (72.8 and 75.4 per cent.), the remaining 11 giving an average of 88.3 per cent. cineole and a maximum of 92.8 per cent.

The variety *Kochii* has been examined regularly since the beginning of 1947. A number of specimens was collected in January and February and two selected typical specimens (one a tree and the other a mallee) were examined at three monthly intervals until the end of January, 1948. In 23 oils analysed, cineole contents ranging from 82.7 to 93.8 per cent., averaging 84.8 per cent., were found.

The variety *plenissima* has been examined over much the same period. In 49 specimens analysed, the cineole contents varied from 83 to 94.8 per cent. and averaged 89.5 per cent. Oils distilled from 20 specimens, collected during the summer months of February and November, 1947, and January, 1948, from 7 sites, give an average cineole content of 89.5 per cent. The summer oils are therefore not distinguishable from those obtained over the entire period.

There is, then, comparatively little difference between the oils from the varieties *borealis* and *plenissima* and, although the average cineole content of the oil from variety *Kochii* is about 5 per cent. less than that of the other two, the range shown by the three varieties is very similar.

Regrowth.

The mallee (K7*a*, var. *plenissima*), which was cut down on 18th January, 1947, gave, on distillation of the dried branchlets, 3.95 per cent. of oil which contained 94.8 per cent. of cineole. Three and a half months later (29th April), the regrowth from the stump was 25 inches high and consisted of numerous fascicles of shoots with 10 to 20 shoots in each. Fifteen months after the original cutting, the regrowth was 35 inches high and gave on distillation 6.4 per cent. of oil containing 91.3 per cent. of cineole.

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5.—INVESTIGATIONS ON THE "LEAF SPOT" DISEASE OF BLACK MULBERRIES CAUSED BY *SEPTOGLOEUM MORI* (Briosi and Cavara).

by

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Read 8th June, 1948.

SUMMARY.

1. A new disease of Mulberry trees is described. The fungus responsible has been isolated and identified as *Septogloeum mori*.
2. The pathogenicity of the fungus has been demonstrated by inoculation experiments.
3. The general morphology, spore types and some of the cultural characters of the parasite are described.
4. Host-parasite relationships have been investigated, attention being given to histopathology, spore dissemination, overwintering of *S. mori*, and the distribution of the disease.
5. The disease has been successfully controlled by spraying either with Lime sulphur or with Bordeaux Mixture. Details of spray programmes are given.

INTRODUCTION.

In Western Australia, the Black Mulberry (*Morus nigra*) was for many years affected by one serious disease only, namely " Bacterial Blight " caused by *Bacterium mori*, (Boyer and Lambert).

In 1943, however, a fungal " leaf spot " disease was also recorded (1). At first, this disease appeared to be of minor importance, but in recent years, it has spread so rapidly that it is now found in most areas of the State where mulberries are grown, and threatens to supersede the " Bacterial Blight " in importance.

The mulberry is of small commercial value in W.A., being grown mainly as single trees in home gardens and orchards ; however, it is much prized as a source of fresh fruit. The following investigation was therefore undertaken early in 1946, to determine the cause of the disease, its method of carry-over, and if possible to confirm measures recommended by the Government Plant Pathologist for its control.

SYMPTOMS OF THE DISEASE.

The disease is confined to the leaves, where it causes regular necrotic areas (1–10 mm. in diameter), with dark brown margins and typically white centres. The area of necrosis is usually surrounded by a chlorotic margin of greater or less extent. Veins immediately surrounding the necrotic area tend to become brown. In the early part of the season, the spot is very small (1–2 mm.) and almost black in colour. The chlorotic region is also small. As the season advances, the spots grow irregularly in area. Each new growth region has its own permanent dark margin, so that the necrotic area eventually becomes marked by a wave-like pattern. (See Plate I.). At the same time, the centre of the spot becomes white, and this white area tends to spread outwards as the necrotic area increases.

The spots may be small and very numerous, or very large, but few in number. In either case they tend to coalesce and kill large areas of leaf tissue.

Plate I.
Mulberry leaf showing the "leaf spot" symptoms caused by *Septogloeum mori*.
Photograph from *Journ. Dept. Agric. W. Aust.*, Vol. XXIV. (Second Series) No. 1, 1947, by courtesy of Department of Agriculture, W.A.

The acervuli appear first as fine black spots in the white centre of the infected area. Later when the epidermis has erupted, the spore pustules show a faint pink colour.

The disease causes premature defoliation leading to dropping of fruit. In a bad season early defoliation results in almost complete loss of the crop.

FUNGUS ASSOCIATED WITH THE SYMPTOMS.

The fungus found to be constantly associated with the above symptoms, was identified as *Septogloeum mori* (Briosi and Cavara). (4) (15).

Initial cultures of the organismn were made by plating out portions of infected leaf material, surface sterilized with mercuric chloride 1:1500 for 1¼ min. ; and washed well with sterile distilled water.

Septogloeum came up constantly in the plates. A number of other fungi occurred less consistently. These included, *Fusarium* sp., *Alternaria* sp., *Chaetomium* sp., *Penicillium* sp., *Verticillium* sp., *Amaurascus* sp., *Phoma* sp., and *Phomopsis* sp. Yeasts and bacteria were sometimes present.

When surface sterilization with calcium hypochlorite was practised, only *Fusarium* sp., and *Alternaria* sp., were occasionally present with the consistently occurring *Septogloeum.*

Phleospora mori (—*Septogleoum mori*) was recorded by McAlpine (7) as the cause of a mulberry leaf spot in Victoria and Tasmania. It is also known to occur in South Australia, Europe (4), North America (4), Central Asia (14), and Belgian Congo (5).

Septogloeum mori has been found to attack white (*M. alba*) (12), red (*M. rubra*) (13), and black (*M. nigra*) (12) mulberries.

DESCRIPTION OF THE FUNGUS.

The Acervulus.

The fruiting body is in the form of an erumpent type of acervulus 1–2 mm. in diameter. The stroma is of compacted dark mycelium, 20μ or more thick. Sporophores are erect, approximately 30μ in length and vary from olive brown to hyaline. Spores of two types were found to be present.

Those on living leaves were hyaline, cylindrical, curvulus, 1–5 septate (rarely 0 or 5) guttulate, dimensions 17μ–53μ x 4.5μ borne singly.

On dead and dying leaves, spores were dark to olive brown, cylindrical, elongate, torulose 1–9 septate, guttulate forms, 20–70μ x 5μ, borne singly.

Study of the hyaline spore type led to the organism being identified as *Septogloeum mori* (2) (4), belonging to the FUNGI IMPERFECTI.

The synonymy for *Septogloeum mori* is as follows : –

Septoria mori Lev. (4) (13)
Septoria moricola Pass. (14)
Fusarium maculans Bereng. (4)
Phleospora mori Sacc. (4) (6) (13)
Phleospora moricola (Pass.) Sacc. (4) (13) (14)
Phleospora maculans All. (4) (15)
Cylindrosporium mori Berl. (3) (11)
Cylindrosporium moricola (14)
Cylindrosporium maculans All. (15)

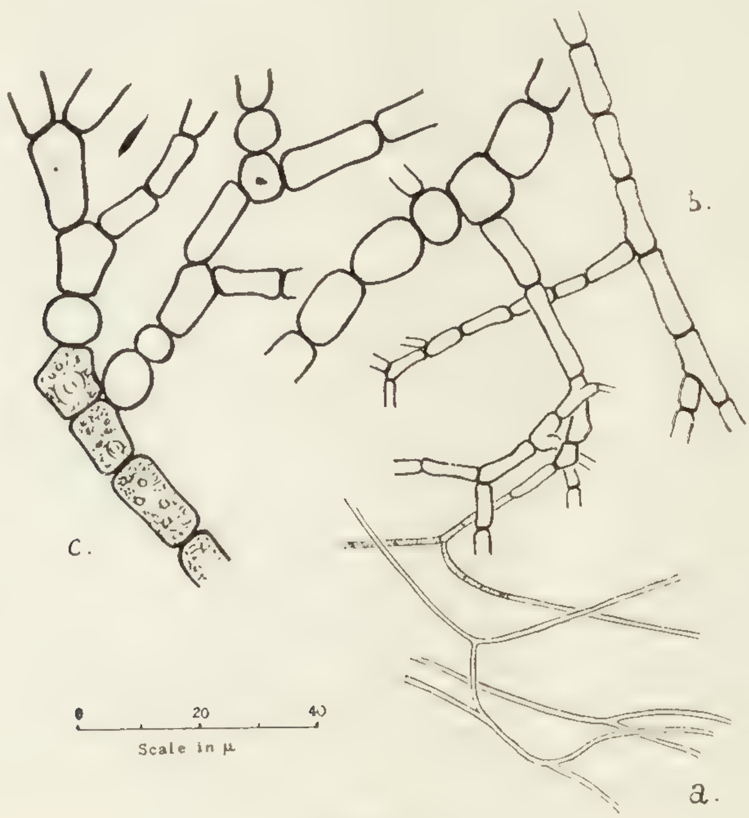
No reference can be found in the literature to the "dark" spore form referred to above. The perfect stage of *Septogloeum* appears still to be a matter for debate. Stevens (11) considers it to be *Mycosphaerella morifolia*, while Ivanoff (5) and Wolf (13) have recorded it as *M. mori.* No confirmatory evidence of either could be found in the course of this work.

The extent of the initial infection of *S. mori* in the mulberry leaf is relatively small, and the invading hyphae sparse, until just prior to spore formation when the mycelium rapidly proliferates beneath the epidermis to form the mass of the stroma.

At this stage, the mycelium exhibits two types of hyphae :—

(a) Fine hyaline hyphae 1–2 μ in diameter, containing a granular protoplast (See text fig. 1a.). This type constitutes the feeding mycelium in the mulberry leaf. In culture, it forms as well a mass of aerial hyphae which completely covers the whole colony, and at times may take on a pinkish to mauve hue.

(b) Thick walled, olive brown mycelium 4–12 μ in diameter generally containing a granular protoplast with highly refractive globules, and large central vacuole.



Text fig. 1.
a. Fine hyaline hyphae.
b. and c. Thick walled dark hyphae.

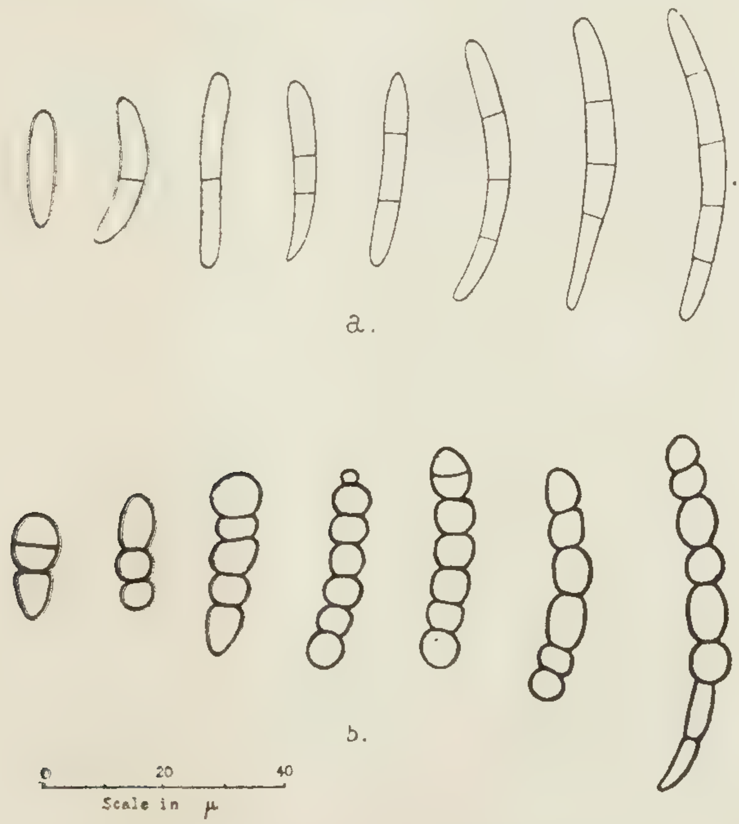
This thick walled mycelium can be separated into two types, one forming rather fine, paler, regular filaments (4 μ in diameter) (See text fig. 1b), the other forming more irregular hyphae, the cells of which tend to be short and globular (8 μ x 10 μ – 12 μ) (See text fig. 1c). In the mulberry leaf these two types or dark mycelium are incorporated in the acervulus. In culture, one or both types may form part of the ground mycelium as well, or in extreme cases, form practically the whole of the fungal body.

The acervulus is more or less circular in shape, but many frequently coalesce to give irregular shaped masses. The stroma of the acervulus is composed of the thickest dark mycelium. This dark mycelium tends to become knotted and packed together to form a pseudo-parenchymatous structure.

The sporophore "layer" is continuous over that surface of the stroma which is adjacent to the epidermis. Wolf (13) describes the sporophores as short, hyaline, 3–10 septate ; but this was not found to be the case here. Investigations of diseased leaf material showed the sporophores to have dark basal cells, which became lighter and thinner walled towards the apex. The apical cell of the sporophore was typically hyaline. The sporophores are erect, and closely packed, they vary in length from 10-40 μ or more, and bear the hyaline spores terminally.

As indicated previously, the spores of *S. mori* are of two types both of which are asexual (a fine hyaline spore, and a thick dark spore). Extreme forms of these spores are distinctly different, and are borne as two separate stages in the life history. The hyaline spores are produced on the living host, while the fungus is actively growing, and they serve to spread the disease during the growing season. These spores have been designated the "Summer" spores, and will be referred to by that name throughout the remainder of the text.

The second spore type (i.e., dark spores) are produced on dead leaves, and in the late autumn have been observed on leaves still attached to the tree. They may be regarded as overwintering forms. This spore type will be referred to as the "Autumn" spore type.



Text fig. 2.

a. Thin walled "Summer" spores.
b. Thick walled dark "Autumn" spores.

The description of the spore types is as follows :—

(*a*) "*Summer*" *Spores*.

Thin walled, hyaline, elongate, multi-septate (0–5) curvulus, guttulate forms approximately 33 μ x 4.5 μ. (See text fig. 2a).

These " Summer " spores are produced both naturally (i.e., on the living host), and in certain culture media (see Table 2.). Spore dimensions (measurements of the length of 100 spores from naturally infected mulberry leaves taken in April, 1946), gave a mean value of 33μ, with a range from $17.5\ \mu$ to 52.5μ. The breadth was more constant, averaging 4.5μ. The number of septa was very variable, being from 0–5 ; the average being 2–3 septa.

(*b*) " *Autumn* " *Spores.*

Thick walled, dark to olive brown, cylindrical elongate, torulose, 1-9 septate, guttulate forms approximately 45μ x 5μ. (See text fig. 2b).

These "Autumn" spores occur on leaves in the late Autumn, and on dead infected leaf material. They have also been found to occur in dried out cultures which initially produced "Summer" spores.

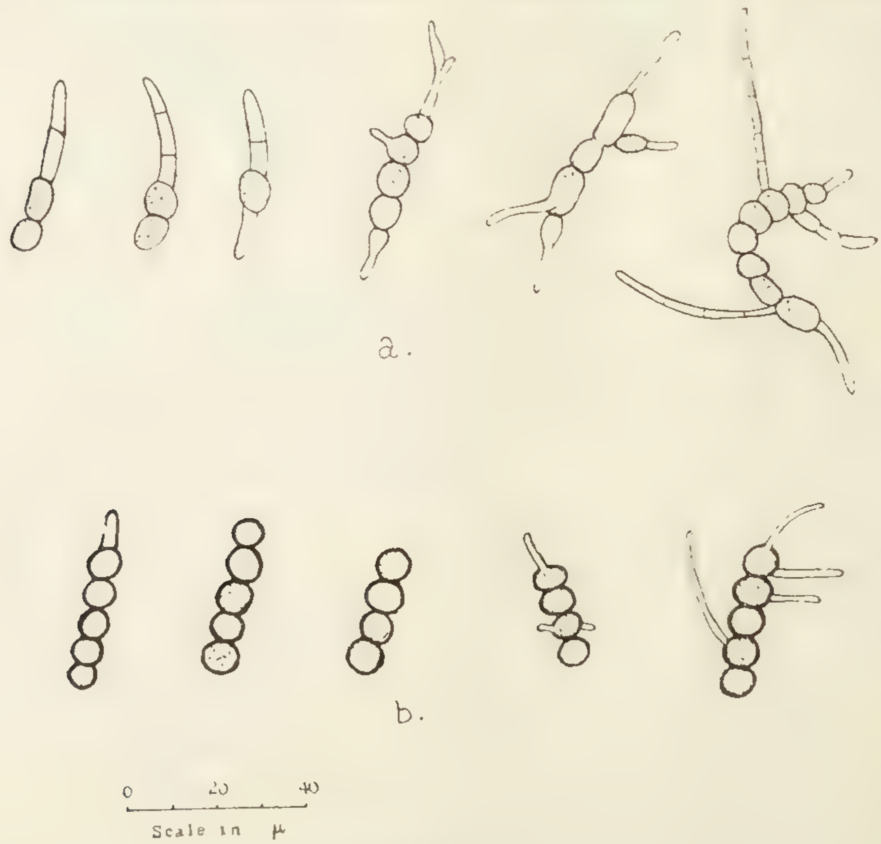
The dimensions of these spores show greater variability than the "Summer" spores. The range in length was from $20–70\mu$, and in diameter from 4.5μ to 5.5μ. The number of septa varied from 1–9. At each septum, the spore tends to be constricted, giving each segment a more rounded appearance than the segments of the "Summer" spores. Typically, the "Autumn" spores are olive brown, but a range of colour to dark purplish grey has been observed.

The "Summer" spores are borne on young leaves but just prior to leaf fall, they begin to be replaced by "Autumn" spores.

CULTURAL CHARACTERS.

1. Spore germination.

Germination is similar in both spore types. Upon placing the spores in water, the spore segments fill out, and tend to round up. Just prior to germination they become densely granular. (See text fig. 3.). In both spore



Text fig. 3.

Germinating Spores.

a. " Summer " spores.
b. " Autumn " spores.

types the germ tubes, which may develop from one or more segments, are fine and hyaline. In " Summer " spores germinated in water the germ tubes were found to anastomose freely with germ tubes of the same or of different spores. Initial branching of germ tubes is not profuse.

Under suitable temperature conditions (20°–30°C), "Summer" spores germinated in distilled water within 24 hours. Difficulty was experienced in getting the " Autumn " spores to germinate in water, but they germinated freely after 36 hours in a mulberry leaf extract.

The optimum temperature for spore germination was found to be approximately 25°C, this being very close to that required for maximum vegetative growth. The maximum temperature for "Summer" spores was found to be 36°C ; they were killed by 24 hours at 38°C. "Autumn" spores survived exposure for 36 hours at 42°C, indicating a higher degree of resistance. "Autumn" spores which had been subjected to winter temperature conditions were 80 per cent. viable when germinated at 24°C. "Summer" spores, kept under laboratory conditions over the winter, were less than 1 per cent viable.

The effect of temperature and type of medium on the germination of spores of *S. mori* is shown in Table 1.

TABLE 1.

Effect of Temperature and Type of Medium on Spore Germination.

Temperature °C.	Per cent. Germination. Summer Spores—24 hours.		Per cent. Germination. Autumn Spores—36 hours.	
	Agar Jelly.	Mulberry Leaf Extract Jelly.	Agar Jelly.	Mulberry Leaf Extract Jelly.
20°	95	98	....	
24°	97	98	....	80
30°	80	95	....	. .
34°	68	75	8	43
36°	0 (a)	0 (a)	0 (c)	0 (c)
38°	0 (b)	0 (b)	0 (c)	0 (c)
40°	0 (b)	0 (b)	0 (c)	0 (c)
42°	....	....	0 (c)	0 (c)

(a) Spores 95 per cent. killed.

(b) Spores all killed.

(c) Spores more than 50 per cent. viable, when retested at 25°C.

Both "Summer" and "Autumn" spores failed to germinate when submerged in agar, or in liquid which was not freely exposed to the air. This indicates their strong aerobic tendencies.

2. Cultures on Artificial Media-Physiology.

Preliminary experiments on the cultural habits of *S. mori* were conducted to give some indication of its requirements.

Considerable variation in the growth of the colony was observed, depending upon the type of media used, its pH value and the temperature of incubation.

Cultures on Potato Dextrose Agar (10) gave a small compact colony, more or less circular, pulvinate with smooth surface and entire margin. With increase in depth of the media, the surface of the colony tended to become rugose. Dark hyphae constituted the feeding mycelium, which was covered by a thin felt of fine white hyaline hyphae—no spores were produced, even when the colony was placed in the sunlight.

Cultural characters for other media used are contained in Table 2, while Temperature relationships are given in Table 3, and pH relationships in Table 4.

TABLE 2.

Media Relationships.

Media.	Growth (Diam. of colony) in 21 days.	Spore Production.	Remarks.
1. P.D.A. ..	12 mm.	–ve.	Small compact growth with fine aerial, and dark ground mycelium.
2. P.D.A. + 0.5% 'Marmite'	14 mm.	–ve.	
3. 'Marmite' P.D.A. + 0.2% NH_4NO_3	29 mm.	+ve., spores of normal size *	Good healthy growth, with rather flat colony of white aerial and dark ground mycelium.
4. P.D.A. + 5% Mulberry leaf Extract †	.. ..	–ve.	Small compact growth as 1 and 2, but with fine grey aerial mycelium, and dark ground mycelium.
5. 5% Mulberry leaf Extract Agar	12 mm.	–ve.	
6. Conn's Agar (8)	23 mm.	Spores a little less than normal in length	Healthy fluffy growth with excess of fine white aerial mycelium.
7. Conn's Agar + 0.5% 'Marmite'	24 mm.	Spores a little longer than normal	Growth a little more dense than with Conn's Agar, also has excess of fine white mycelium
8. Conn's Agar + 1% Mulberry leaf Extract	23 mm.	Spore size normal	Much darker denser growth than 6 and 7, with great quantity of dark ground mycelium and greyish aerial mycelium.
9. Conn's Agar + 2% Mulberry leaf Extract	25 mm.	Spore size normal	
10. Conn's Agar + 4% Mulberry leaf Extract	25 mm.	Spore size normal	
11. Shear's Corn Meal Agar (9) .	15 mm.	–ve.	Small compact growth with fine white aerial and dark ground mycelium
12. Standard Agar (8)	17.5 mm.	–ve.	Small more sparse growth with practically no dark mycelium
13. Leonian's Agar (9)	6 mm.	–ve.	Very restricted compact growth, with fine aerial and dark ground mycelium

* Normal spore length was taken as the average length produced naturally—i.e., 33μ x 4.5μ.

† "A 5 per cent. mulberry leaf extract was made by boiling 50 gms. of dried ground leaf material with water for 20 minutes ; this was filtered and made up with water to 1 litre. When combined with other media, this extract was used in place of water."

TABLE 3.

Temperature Relationships.

(Conn's Agar used as standard media, pH adjusted to 4.5).

Temperature.	Growth (Diam. of Colony) in 16 days.	Remarks.
10°C	0.0 mm.	No growth, but colony not killed.
22°C	21.9 mm.	Good growth, production of spores within 12 days.
30°C	12.0 mm.	Only white growth ; no spores produced.
35°C	0.0 mm	No growth, culture not killed.
40°C	0.0 mm	Killed within 48 hours at this temperature.

The above table indicates that temperature has a marked effect both on mycelial growth and on spore production.

TABLE 4.

pH Relationships.

(Using Conn's Agar at 22°C.)

pH of Media.	Growth (Diameter of Colony) in 24 days.	Remarks.
4.2	24.0 mm.	Culture healthy with abundant fine white mycelium. Good spore production.
5.0	28.7 mm.	Culture healthy with characteristic ragged edges. Very good spore production.
6.0	29.9 mm.	As for pH5, but spores slightly larger.
7.0	20.1 mm.	Dark ground mycelium in excess of light aerial. Spore production small. Actual growth more sparse.
8.0	23.2 mm.	As for pH7, but actual growth much more sparse. Spore production occurs much later, and is less abundant than for pH ranges between 4.2 and 8.0.
9.0	22.1 mm.	

This table indicates that a pH between 5 and 6 is the most suitable. It may be noted that *S. mori* grows well both in very acid and in very alkaline media.

3. Spore Production in Culture.

"Summer" spores produced in culture were found to be morphologically almost identical with those produced naturally, although some difference in size was observed.

The connection between spore types was ascertained. In older cultures which had been taken from a single hyaline spore culture, a range of types from the hyaline "Summer" spore to the dark "Autumn" spore was observed. (See text fig. 4.).

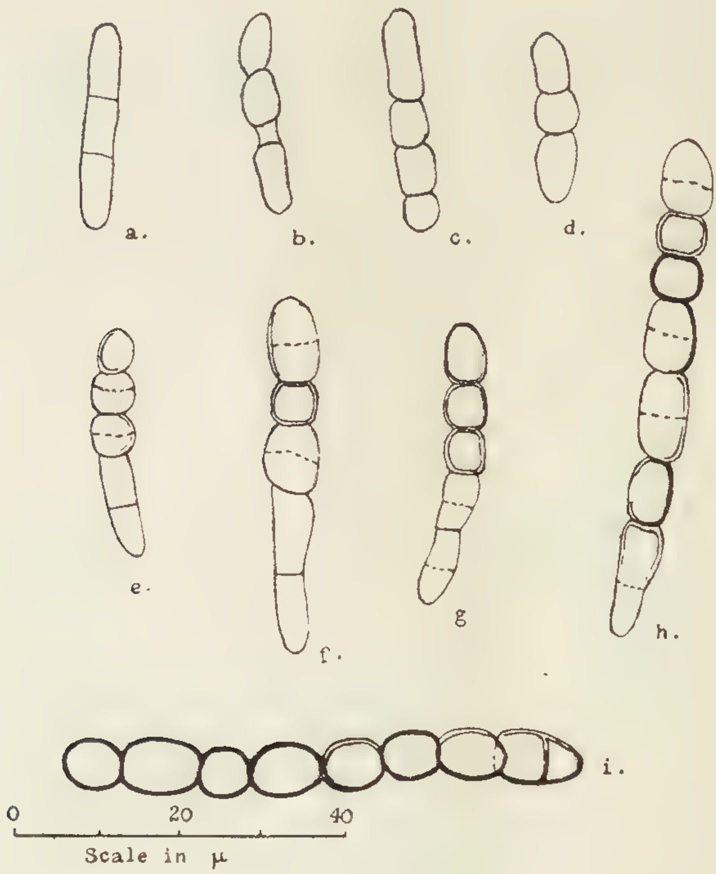
MODE OF INFECTION.

The relationship between host and parasite was investigated by sectioning both naturally and artificially infected material.

In microtomed sections of mulberry leaf material, that had been artificially inoculated for 28 hours before fixing, germ tubes of *S. mori* were observed entering the stomates. No indication of cuticular penetration was found.

Inoculation, in the field, of leaves which were kept under humid conditions for 28 hours, showed, upon examination, germ tubes entering the stomates.

Further experiments in the laboratory, confirmed the results in the field. Stomata are found on the lower surface of the leaf only, and infection occurred only on leaves inoculated on the lower surface.



Text fig. 4.
Stages in the formation of "Autumn" spores of *Septogloeum mori.*

HISTO-PATHOLOGY.

Using microtomed sections, the course of infection was traced, and found to be as follows :—

After the germ tube penetrates the host, the mycelium first invades the spongy mesophyll. Its growth is mostly intercellular and in course of time the fungus spreads through most of the host tissue. It invades particularly the parenchyma sheath of the vascular bundle. (See text fig. 5).

Throughout the whole of this vegetative growth, the mycelial strands are quite sparse. They extend well beyond the limits of the necrotic spot, possibly to the extent of the chlorotic area.

About the tenth day after infection, the mycelium in the centre of the diseased region tends to anastomose beneath the epidermis to form the acervulus. Acervuli occur commonly on the upper surface of the leaf, but they may be formed on the lower surface also.

This mass of anastomosing tissue replaces the inner and side walls of the epidermal cells, while the outer wall and cuticle remain intact. From this mass of mycelium, the acervulus is formed, and it produces spores irrespective of the external moisture conditions.

Several acervuli are produced within each "spot."

Late in Autumn the infected areas bear the "Autumn" spores. The "Autumn" spores borne on the acervulus of the dead leaf form a very compact mass, which tends to remain as such, and they are only released with the decomposition of the leaf.

Text fig. 5.
T. S. of mulberry leaf showing the invasion of the vascular sheath by mycelium of *S. mori* and the production of tannin in the blackened areas.

SPORE DISSEMINATION.

By exposing glycerined slides, evidence was obtained that the "Summer" spores of *S. mori* were wind borne and that they were released only during rainy weather.

Given suitable moisture conditions, the epidermis above the acervulus blisters, and, with continued high humidity, bursts, exposing the faintly pink pustules of spores.

Dissemination of "Autumn" spores is also believed to be by wind. As the spores were found lodged in all conceivable crevices of the trees it seems unlikely that any other agency could distribute them so well. The "Autumn" spores are released by the decomposition of the leaf material.

OVERWINTERING OF *S. MORI*.

The overwintering of *S. mori* is carried out by the thick walled "Autumn" spores previously described.

A search was made for a sexual stage of the fungus. Infected leaves which had fallen naturally, were trapped beneath wire netting and allowed to decay in that condition, while other leaves were held in a damp condition in the laboratory.

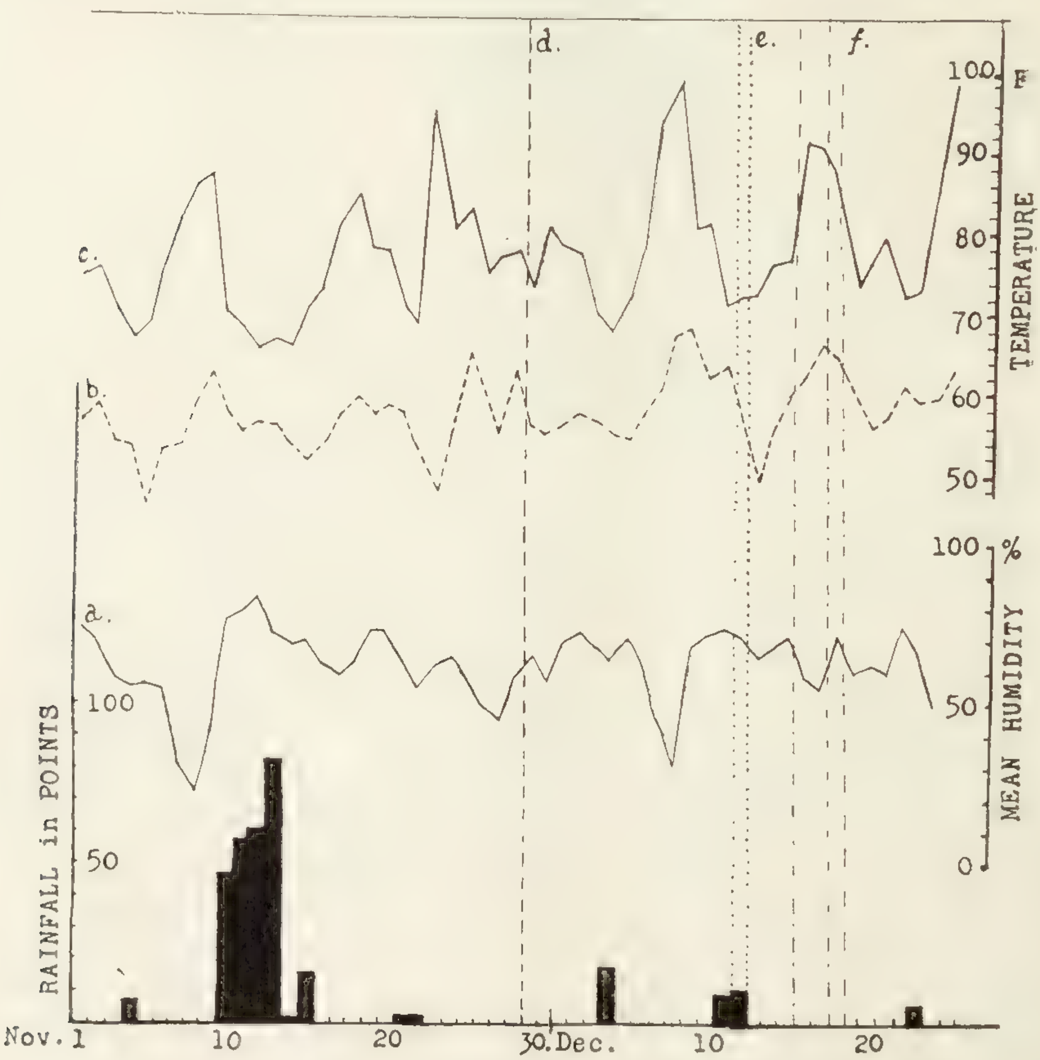
The fungal flora of the above leaves was investigated, paying particular attention to regions of infection. In these regions numerous pustules of "Autumn" spores (of *S. mori*) were consistently found. The fungi most commonly associated with them were species of *Phoma* and *Alternaria*.

Fungi of less frequent occurrence were species of *Fusarium, Phomopsis, Pleomassaria, Amaurascus*, and a slime mould. Neither *Pleomassaria* nor *Amaurascus* could be shown to be related to *Septogloeum mori*, as both produced only their sexual stage in culture. There was no other sexual form found, and no trace of the sexual stage of *S. mori* in dead leaf material.

In a further search for the sexual phase of *S. mori* dead twigs and wood, lenticels (especially those diseased), wood cankers, buds and leaf scars were closely examined but without result. " Autumn " spores only were found deposited in most of the regions investigated.

COURSE OF THE DISEASE.

In the season, 1946–7, the mulberry leaf spot first appeared in the metropolitan area at the end of November. Extensive rains fell early in November, accompanied by cool weather and high humidity. Eighteen days after the first fall of rain the disease was recorded. (See text fig. 6). This outbreak



Text fig. 6.

Spore release of *S. mori* in relation to climatic conditions

a. Mean humidity.
b. Minimum Temperature.
c. Maximum Temperature.
d. First appearance of natural infection of *S. mori*.
e. Times of natural release of spores of *S. mori*.
f. Times when no release (natural) could be detected.

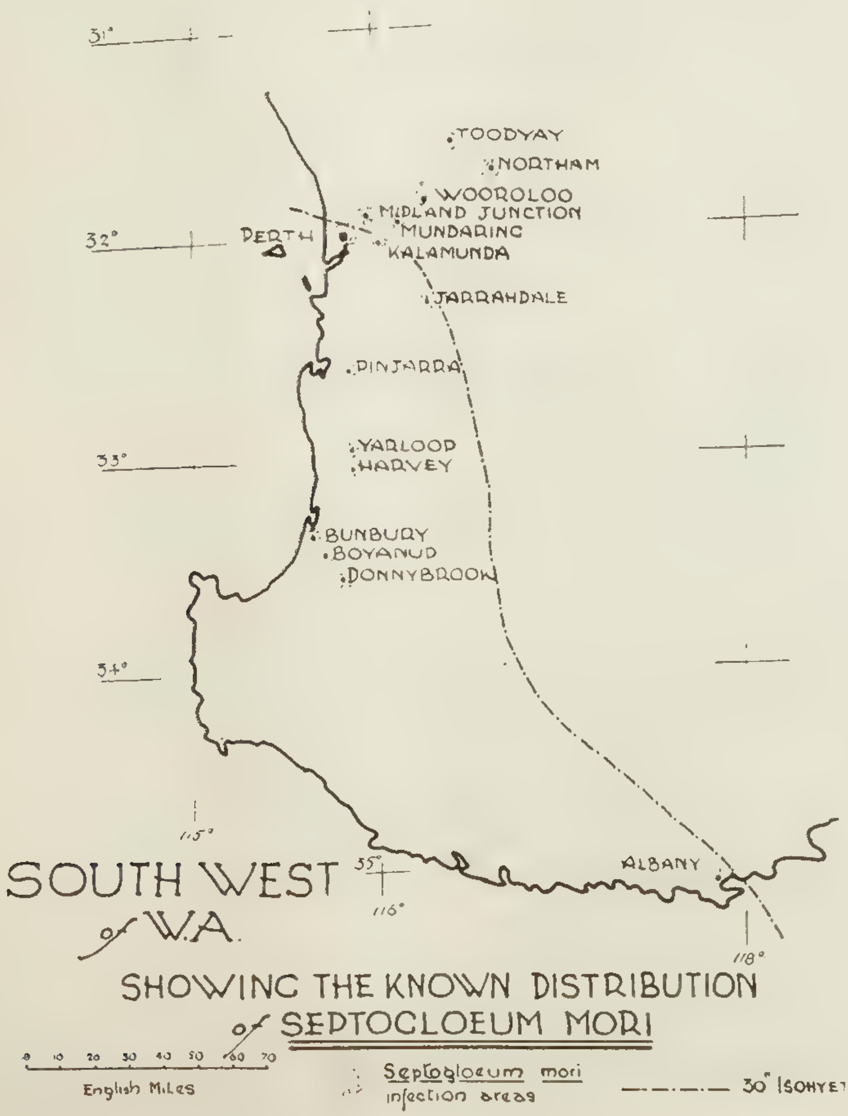
was extensive throughout the metropolitan area, none of the trees under observation escaping. Further rains fell early in December, and by Christmass the trees were nearly as badly infected as they had been at the end of 1945–46 season when this investigation was commenced. Scarcely any leaves were left without spots, and large areas of many infected leaves were killed.

By early January, many of the control trees were practically bare of foliage. Others were not so badly affected, but even there, de-foliation had commenced.

The onset of the disease appears to have been suspended over the hot, dry January period, the condition of the trees remaining much the same as they were in December.

DISTRIBUTION OF THE DISEASE.

In the South West, the disease has been recorded in early summer, occurring before fruit ripening stage. It has a fairly extensive distribution, (see text fig. 7), mainly occurring in the 30 in. to 40 in. rainfall area, where temperatures during November and December are low and humidity high.



Text Fig. 7.

The most northerly regions in which the disease has been recorded are Toodyay and Northam. Both these towns lie well within the 20 in. to 30 in. rainfall belt, but being situated on a river have slightly higher humidity than the surrounding districts.

This distribution suggests that it is a disease of cooler, more humid regions. It may be noted that this disease also occurs in France under moist conditions (3).

INOCULATION EXPERIMENTS.

After isolation of the organism, inoculation experiments were carried out to test for pathogenicity.

Mature trees in the field together with three-year old trees kept under glass house conditions were used for the experiments.

Technique.

Sterile bottles were placed over test leaves, the necks protected with cotton wool, and the bottles supported to prevent strain on leaf or stalk.

Leaves selected were well shaded, so as to avoid direct rays of the sun.

The leaves under test were kept in the sterile bottles for ten days prior to inoculation to make sure that they were healthy.

Spore suspensions used were made as follows :—

(a) Suspensions of " Summer " spores were made by flooding mature cultures with sterile distilled water, and carefully disturbing the surface mycelium so as to release the spores, without breaking off the aerial mycelium.

(b) Suspensions of " Autumn " spores were made from naturally infected leaf material, as no culture was entirely free from " Summer " spores. This leaf material was taken from naturally infected leaves which had been trapped beneath wire-netting and allowed to decay naturally. The spore masses were carefully dissected out in distilled water. This suspension was agitated to separate the spores.

Using sterile pipettes, the spore suspension was carefully dropped on mapped portions of each leaf (both upper and lower surfaces). The rough nature of the epidermis allowed a relatively large drop of inoculum to remain in situ.

In inoculation tests using " Summer " spores, typical disease symptoms developed within 10–14 days, while control leaves remained healthy. In practically all cases, spores were produced within 12 days.

A similar experiment was carried out on an old tree in the field, the inoculated leaves being situated well towards the centre of the tree, to shade them from the sun. With this experiment the results obtained were similar to those of the small trees, but the disease was produced in a shorter time. This difference in time could perhaps be attributed to temperature differences.

In tests using " Autumn " spores, positive results were obtained, but the diseased areas took twenty (20) days to produce spores. The occurrence of hot dry weather during this experiment is believed to be responsible for the long incubation period.

THE COURSE OF SYMPTOMS FOLLOWING ARTIFICIAL INOCULATION.

The first visible signs of infection following artificial inoculation occurred between the fifth and eighth days when chlorotic areas with diffuse margins became apparent. This was followed within the next two days by the appearance of a slightly discoloured spot in the centre of the chlorotic area. This spot enlarged and darkened until by the 10–14th day, it was dark brown in colour, 2–3mm. in diameter. It forms the original necrotic area. If weather conditions are suitable once this stage has been reached, the epidermis erupts and the spores are exposed.

Further growth of the spot is slow. It retains the halo of chlorotic tissue, while the centre of the spot becomes white, (the whole of the internal leaf tissue is disintegrated and partially absorbed by the parasite, so that only the upper and lower epidermis remain intact).

When the growth is temporarily suspended, the margin of the spot becomes much darker, becoming impregnated with tannin, which remains within the necrotic area when growth of the parasite proceeds.

The actual manifestation of the symptoms was found to vary with the environmental conditions. Infection under cool, moist conditions (on vigorously growing leaves) gave small dark spots with little chlorosis, while hot, moist conditions gave extensive chlorosis and a very pale spot.

CONTROL MEASURES.

In experiments designed to control this leaf spot disease, two sprays were tested :—

(a) Lime-sulphur.
(b) Bordeaux mixture.

TABLE 5.

Spray Schedule.

Tree No.	Time of Spray.	Spray Used.	Strength of Spray.
I.	At Bud Movement 28–9–46	Lime-sulphur	1/15 (Polysulphide content* = 1.44 %)
	After Bud Burst 14–10–46	do. do.	1/50 (Polysulphide content = 0.432 %)
II.	At Bud Movement 28–9–46	do. do.	1/15 (Polysulphide content = 1.44 %)
	After Bud Burst 14–10–46	do. do.	1/50 (Polysulphide content = 0.432 %)
	After Fruit Set 18–11–46	do. do.	1/100 (Polysulphide content = 0.216 %)
III.	At Bud Movement 28–9–46	Bordeaux mixture....	6 : 4 : 40.
	After Bud Burst 14–10–46	do. do.	3 : 4 : 40.
IV.†	At Bud Movement 28–9–46	do. do.	6 : 4 : 40.
	After Bud Burst 14–10–46	do. do.	3 : 4 : 40.
	After Fruit Set 18–11–46	do. do.	2 : 4 : 40.

In all cases calcium caseinate was used as a spreader at the rate of ½ lb. per 40 gallons of spray.

* Estimation of polysulphide content of the stock Lime-sulphur was kindly made by Mr. A. R. H. Cole (Research Officer, Department of Chemistry, University of W.A.).

† This tree was within 20 yards of an unsprayed control tree.

As there were only six trees in the same vicinity (i.e., Nedlands district) available for spraying, treatment was limited to four trees sprayed, two with Lime-sulphur, and two with Bordeaux mixture, while two trees were kept as controls.

The distribution of these trees was such that the distance between the two most widely separated trees was $\frac{5}{8}$ of a mile, and no two trees were more than $\frac{7}{16}$ths of a mile apart.

Times of spraying were :—

(a) Bud Movement (28–9–1946).

(b) After Bud Burst (14–10–1946).

(c) After Fruit Set (18–11–1946).

The days on which spraying was carried out were all fine and clear, with only light winds. The spray was applied between 10 a.m. and 4 p.m. Complete trees were sprayed, particular attention being given to the trunk.

The spray schedule is outlined in Table 5.

The disease first appeared on the control trees on the 28th November, 1946, while all four sprayed trees were completely free from disease. Data relating to the occurrence of the disease on the experimental trees is given in Table 6.

TABLE 6.

Tree No.	Spray.	Date.	Conditions of Tree. Remarks.
I.	Lime-sulphur	28–11–1946	No trace of disease.
	Treatment with 2 sprays	2–1–1947	Traces of disease.
		16–2–1947	No further spread of disease on tree.
II.	Lime-sulphur Treatment	28–11–1946	No trace of disease.
	with three sprays	2–1–1947	No trace of disease.
		16–2–1947	No trace of disease.
III.	Bordeaux mixture . .	28–11–1946	No trace of disease.
	Treatment with 2 sprays	2–1–1947	Traces of disease.
		16–2–1947	Spread of disease on tree.
IV.*	Bordeaux mixture .	28–11–1946	No trace of disease.
	Treatment with three	2–1–1947	Traces of disease.
	sprays	16–2–1947	No further spread of disease on tree.
V.	Control tree unsprayed	28–11–1946	Disease first apparent.
		2–1–1947	Disease well distributed over whole tree.
		16–2–1947	Disease much as on 2–1–1947 but defoliation had begun.
VI.	Control tree unsprayed	28–11–1946	Disease first apparent.
		2–1–1947	Disease distributed over whole tree, but particularly in one area.
		16–2–1947	Disease much as 2–1–1947, except that the area of tree which was badly infected at that time, now was practically devoid of foliage.

*This tree was within 20 yards of control tree V.

All trees used in the spraying experiments had been badly infected in the previous season, and it was assumed that all trees would have an approximately equal chance of further infection.

One control tree (V) was in the same garden as one sprayed tree (IV), the other trees were all solitary, and fairly evenly distributed.

This Spray Programme in all cases gave excellent control of the disease, apparently by destroying all overwintering inoculum held on the non-deciduous portions of the tree.

In this connection it may be noted that Masera, (6) advocates pruning of the young parts of the tree to reduce infection. This probably results in a reduction in overwintering spores, giving an effect similar to that of the spray treatment.

Removal and burning of all deciduous portions of the tree as soon as shed would remove the bulk of the overwintering inoculum before it had a chance to be dispersed, and so greatly reduce the potential infection source for the new season.

Of the sprays used, Lime-sulphur with three applications was the most effective ; and this, combined with the destruction of all deciduous portions, should go far towards the control of the disease.

ECONOMIC ASPECT.

As previously indicated mulberry trees have little economic value in this State. (In the 1945–46 season only 190 bushels, valued at approximately £950, passed through the markets). They are mainly grown in home gardens as a source of fresh fruit. In other countries, the mulberry tree is important because of its relation to the silk industry, and Masera (6) believes that the diseased leaves are toxic to silk worms. However, mulberry leaves sprayed with Lime-sulphur were found to be unpalatable to the silk worm (no record was made of the palatability of leaves sprayed with Bordeaux mixture).

It is apparent that sprayed trees retain their fruit load much better than the unsprayed control trees ; also, the sprayed trees appear to be almost free from "Bacterial Blight" as well as from the "leaf spot" disease. However, Bordeaux mixture left an undesirable residue on the fruit.

Estimations of the cost of applications of the sprays were made, and these were as follows :—

Lime-sulphur.—8s. 6d. approximately per tree for three sprays.

Lime-sulphur.—7s. approximately per tree for two sprays.

Bordeaux mixture.—3s. approximately per tree for three sprays.

These estimates include the calcium caseinate spreader.

ACKNOWLEDGMENTS.

The author is indebted to Mr. W. P. Cass-Smith, Government Plant Pathologist of the Department of Agriculture, W.A., for suggesting the subject for this investigation ; for advice during the whole investigation ; loan of apparatus and access to Departmental records, and also for criticism of the text. To Miss A. M. Baird and Miss O. Goss for valuable assistance and advice. Also to Mr. A. W. Brown, Mr. Dowell, Mr. J. Sherzinger and Mrs. M. R. Thomson who made their trees available for spraying.

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6.—NOTES ON LATERITE IN THE DARLING RANGE NEAR PERTH, WESTERN AUSTRALIA.

By

S. E. Terrill, B.Sc., A.A.C.I.

Read 8th June, 1948.

Laterite is widespread in Western Australia and it has been reported on by geologists and pedologists who have examined large tracts of country in connection with mining and agricultural activities. Mineral chemists and mineralogists have also added to our knowledge of the subject.

It is not intended to review this literature here, but to place on record certain results of work done by the present author in the study of laterite as a spare-time pursuit and to draw attention to certain inferences which result therefrom. The work done on an exposure of laterite at Parkerville and reported in this paper, formed the basis of a contribution to a symposium on "Laterite in Australia" at the Perth Meeting of the Australian and New Zealand Association for the Advancement of Science held in August, 1947.

The literature concerning laterite abounds in hypotheses of origin and these may be divided into two main groups. One group of hypotheses involves solution, transport to a new site and re-deposition thereat of the laterite constituents. The other group constitutes variations of the one theme whereby laterite is deemed to have been left behind when the non-lateritic constituents, that is, the whole of the combined silica, the lime, magnesia and alkalies, have been removed in solution.

Those hypotheses which involve the movement of lateritic constituents in solution may be further grouped according to the direction of the movement of the laterite-forming solutions and the nature of the influences governing that movement.

The "capillarity school" of thought envisaged the movement of these solutions upwards from the water-table under the influence of capillary forces. Having reached the surface, or come near thereto, evaporation and/or oxidation leads to the deposition of the oxides of iron and aluminium, or, alternatively, the uppermost layers of the soil are replaced by these oxides. Simpson (1912), Woolnough (1918) and others considered capillarity to be the chief influence controlling the movement of laterite-forming solutions.

Another hypothesis, advanced by Prescott (1931), involves the downward movement of iron- and aluminium-bearing soil-waters under the influence of gravity: upon reaching a lower horizon, changed conditions of soil acidity cause the precipitation of laterite constituents as an illuvial horizon.

A third school of thought accepts the views advanced by Campbell (1910, 1917). Those who accept this hypothesis consider that iron or both iron and aluminium are taken into solution in percolating meteoric waters which,

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under gravitational influences, move downwards to the water-table and then laterally in the zone of saturation: seasonal oscillation of the water-table causes alternate wetting and drying-out of a lower zone of the soil profile, leading to the deposition therein of iron and/or aluminium oxides.

It might be expected that a detailed examination of laterite exposures where railway or road cuttings and the like pass right through the laterite into the underlying materials might yield evidence of a critical nature which may lead to the selection of one or another of the hypotheses as applying to the Darling Range laterite. If, for example, the hypothesis involving solution, transportation laterally and re-deposition holds, it would not be expected that a sharp and distinct boundary would exist between laterite over a basic dyke and that overlying the granite traversed by such dykes, this being essentially the geological nature of the Darling Range. Further, if the distinctive structure of the basic dyke rock should appear in the laterite, either there must have been a selective replacement of the parent rock by the laterite constituents, or the laterite must be a skeletal body left upon the removal of those constituents of the parent rock which are not present in the laterite. Again, should the laterite retain the structure of the parent rock and should its alumina/ferric oxide ratio be approximately the same, it is considered that no hypothesis involving solution, transport to a new site and re-deposition can be accepted as indicating the origin of that particular occurrence. Alternatively, if the first products of weathering form a plastic clay, swelling and shrinking during alternate water-saturation and desiccation would be expected to destroy very quickly any vestige of the structure of the parent rock: this would not be expected to occur, however, should a non-plastic kaolin body be formed in the first place.

These are but a few of the possibilities, each of which is dependent upon the manner of evolution of the laterite. The literature concerning laterite is a prolific source of such possibilities, and a consideration of these enables one to select suitable exposures for detailed study, exposures which might be expected to yield information of a critical value.

The basic dyke rocks have a readily recognisable, distinctive structure, should it be preserved in laterite derived therefrom, whereas the granite and granitic gneisses generally have not. Consequently, in the road and rail cuttings and gravel pits of the Darling Range, a search was made for massive laterite which could be seen to overlie recognisable basic-dyke rock or in which remnants of the basic dyke could be recognised.

North of the present railway station at Mount Helena there is an old railway cutting where there is exposed an excellent example of the weathering of a basic dyke cutting through the granite, with what appears to be laterite developed over both. On the surface of the ground near-by it was not possible to detect any difference between the weathering product from the granite and that from the basic dyke rock. In the sides of the cutting, however, the position and attitude of the parent basic dyke are clearly evident and the boundary between what is probably laterite derived from the basic dyke and that formed on the granite is sharp and distinct. The product of weathering derived from the basic rock is markedly different from that over the granitic rocks: it is very dark brown as compared with the light yellowish brown of the laterite over the granite; it is denser and more even in structure and preserves the system of cracks formed during the initial fracturing and spheroidal weathering of the rock. The laterite overlying the granitic rocks

is thin and is underlain by soft, friable, gritty clay and concretionary structures are well developed in it. No further work has been done on this exposure because the profile is not sufficiently exposed to give information on the nature of the materials beneath the laterite formed over the basic dyke.

At Parkerville, however, there is an exposure that does not suffer from this deficiency. In the vicinity of the Public Hall near the railway station and crossing, a number of pits have been dug to obtain laterite and clay for road and other civic amenities, and to provide level ground alongside the hall. In doing this, a face was cut which reveals the top twelve feet or so of the profile of a weathered basic dyke rock, a typical quartz-dolerite with the characteristic ophitic texture of this rock-type (*see* Plate II, fig. 1). An analysis of the rock is given in Table 1.

TABLE 1

	Dolerite.	Laterite.
	%	%
SiO_2 (total)	50.63	15.83
(free)	....	(5.66)
(combined)	....	(10.17)
Al_2O_3	13.20	31.68
Fe_2O_3	1.70	24.95
FeO	10.06	2.52
MnO	0.17	n.d.
MgO	7.63	0.62
CaO	12.27	0.01
Na_2O	2.00	0.14
K_2O	0.16	*nil*
H_2O-	0.03	2.69
H_2O+	0.59	19.55*
TiO_2	0.91	2.07
P_2O_5	0.15	0.09
	99.50	100.15
Molecular Ratios :		
Combined silica/alumina	....	0.54
Alumina/ferric oxide†	2·05	1.99

* By ignition loss.

† The ferrous oxide of the quartz-dolerite in excess of that of the laterite is regarded as converted into ferric oxide by the weathering processes.

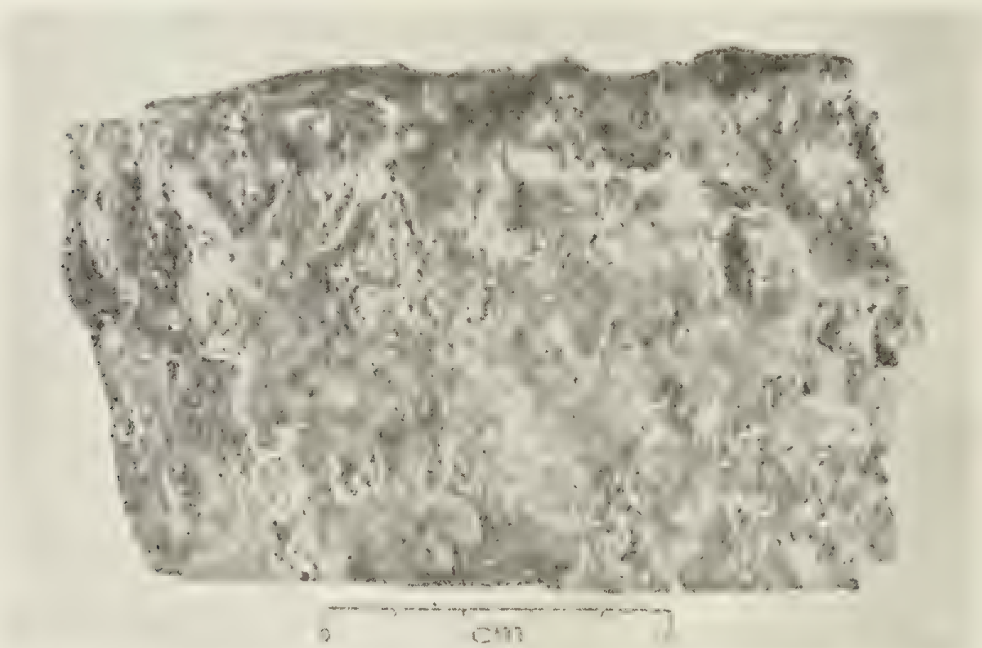
Analysts : S. E. Terrill and D. Burns.

The top eighteen inches to thirty inches of the profile is loose and rubbly with much root and organic matter. The stones of the rubble are rarely more than an inch and a half across and, when broken across, are evenly coloured a very dark brown—no banded concretions were seen in this spot. Below the rubbly top horizon there is a layer three to four feet thick, of porous to dense, mottled, fairly hard laterite, rather darker than is usual in laterite overlying granite, but otherwise similar to some of the forms in which that laterite occurs. The laterite over the basic dyke has the same mode of occurrence as, and appears to be continuous with, the quite normal-looking laterite exposed in pits nearby and considered to overlie granitic rocks. No evidence was found to suggest that the two varieties of laterite were not formed contemporaneously and under the same conditions. The jointing of the parent quartz-dolerite and evidences of its spheroidal weathering are clearly preserved in the laterite in some parts. The laterite is mottled in colours of red, yellow and brown, the mottling and porosity giving the rock a banded appearance, the banding following the spheroidal weathering pattern,

A thin vertical crack through the laterite was observed to be filled with structureless lateritic material and, embedded in it, small nodules up to about half an inch across and similar to those in the top rubbly or gravelly horizon. The base of the laterite layer is six to seven feet below the original land surface ; it is fairly clearly defined and rests upon a coarsely mottled clay. The bottom of the laterite is not at all even for it projects down into the clay for two or three feet in one place where there is the development of laterite some six to nine inches thick on either side of a joint plane : this joint plane does not appear to continue on down into the mottled clay.

The mottled clay underlying the laterite is a structureless, very pale bluish grey or greenish blue-grey, non-plastic kaolin in which there are harder ferruginous lumps. These are mostly two to four inches across, brick red to bright dragon's blood red in colour, harder than the thumbnail but easily scratched with a knife : the lumps show no definite structure.

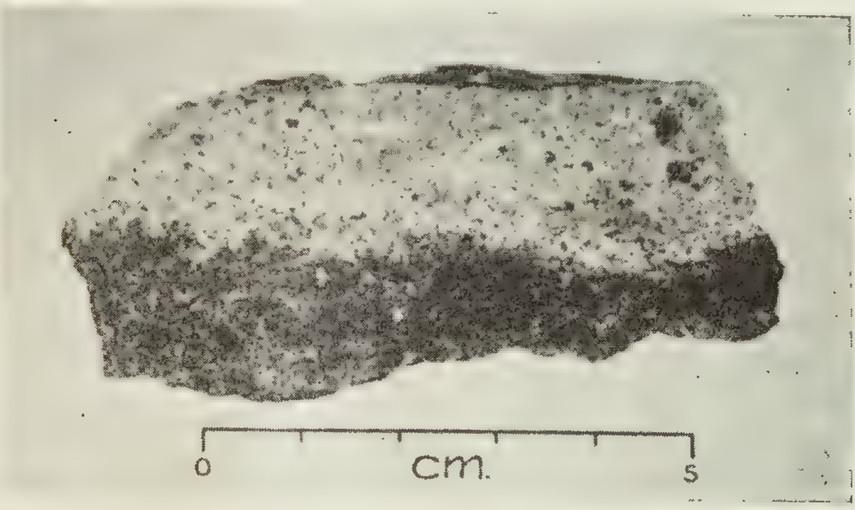
Remnants of the parent quartz-dolerite are to be observed in the profile. One large boulder, four to five feet across, can be seen at the right of the face shown in Plate I, fig. 1. Above this, there is also a much smaller one at about the middle of the laterite layer. The specimen shown in text-fig. 1 was taken from a point about eighteen inches to the left of the small boulder which is the core of the spheroidally weathered block from which the specimen was taken. At the spot where the specimen was taken the colour banding and solution channels are vertical.



Text fig. 1.—"Vermicular" laterite derived from quartz-dolerite, oriented as it was in the laterite horizon.

The large boulder is partly in the laterite stratum but is mostly in the underlying clay horizon. A narrow zone of laterite has developed all around it and is clearly continuous with the fresh quartz-dolerite. This crust is considered to be illustrative of the first-formed primary laterite and a sample was taken for analysis and microscopic examination. Taken from another boulder, the specimen shown in text-fig. 2 illustrates the intimate nature of the junction of quite fresh quartz dolerite and fully developed laterite.

Microscopic examination of the thin sections shows the laterite to be very porous indeed. It consists of pale yellow, lath-shaped relicts of plagioclase felspar in a reddish brown, apparently amorphous mixture of cliachite, hematogelite and limonite ; this latter mixture being quite isotropic between crossed nicols and is considered to have been derived from the ferro-magnesian minerals of the parent rock. The plagioclase relicts consist of microcrystalline material which is considered to be mainly gibbsite with possibly some kaolinite. The faintly yellow non-pleochroic crystals of gibbsite are mostly between five and ten microns across and exhibit a moderate to rather strong anisotropism between crossed nicols. The identification of this material as gibbsite rests upon rather difficult optical work, supplemented by a dyestuff test using the solution of alizarin S (sodium alizarin sulphonate) recommended by Hardy (1931). In some respects this laterite is very similar to the laterite derived from diorite described by Max Bauer (1898).



Text fig. 2.—Small specimen showing the intimate nature of the contact of quartz-dolerite and laterite.

The analysis of the laterite is given in Table 1 and shows that about seventy per cent. of the alumina present is in the form of one or another of the hydrated oxides. Plate II, figs. 2 and 3, are photomicrographs of thin sections of the laterite crust and show the microcrystalline relicts of the plagioclase felspar laths of the parent quartz-dolerite. It will be noted that the structure of the parent quartz-dolerite is very well preserved indeed and that there has been remarkably little disturbance of the alumina/ferric oxide ratio in the course of the weathering of the quartz-dolerite to laterite.

A thin-section was also prepared from the specimen taken from the middle of the laterite stratum and referred to above. This section shows that even here, much of the laterite still retains the structure of the parent rock which is discernible in parts of the massive laterite horizon, even with the unaided eye. As would be expected, there is also much evidence of the filling of general porosity and of solution channels, as shown in the top right-hand quadrant of Plate II, fig. 4, which shows a portion of the slide referred to.

Taking the analyses of the parent rock and the laterite in conjunction with the preservation in the laterite of the structure of the quartz-dolerite and the development of the laterite virtually without disturbance of the alumina/ferric oxide ratio, it is considered that this evidence indicates a process of elimination, in solution in percolating meteoric waters, of those

constituents of the parent rock not still found in the laterite. The possibility of a sort of selective metasomatic replacement of the quartz-dolerite by a mixture of oxides exactly similar in proportions of aluminium and iron to the parent rock is too remote to merit further consideration here, particularly in view of the relatively mobile character, in soils, of iron as compared with aluminium.

This conclusion has far-reaching implications, for no evidence has been found to indicate that the adjacent laterite overlying granitic rocks was not formed in the same manner and under the same conditions as was the laterite examined. It strongly suggests that the laterite of the Darling Range was formed in the manner indicated and not in the way outlined by Stephens (1946).

Hanlon (1945) has described laterite occurrences in New South Wales which are similar to this Parkerville occurrence in that the laterite retains the structure of the parent basalt and at the same time shows little, if any, disturbance of the relative proportions of alumina and ferric oxide. Martin and Doyne (1927), likewise, have described a similar occurrence in which the laterite is derived from norite.

Grateful acknowledgment is made of the assistance given by my colleague, Mr. D. Burns, of the Government Chemical Laboratories, who carried out part of the analytical work on both the quartz-dolerite and the laterite ; the balance of the work was done by the author. Thanks are also due to Mr. H. P. Rowledge, then Deputy Government Mineralogist, now Director of the Laboratories, for his permitting Mr. Burns to assist the author in this way.

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PLATE I.

Fig. 1.—Parkerville Tennis Courts, Easterly face showing laterite overlying mottled clay. Large quartz-dolerite boulder at extreme right. Loose surface material has been removed from the left half of the exposure shown.

Fig. 2.—Closeup of profile exposed at right end of Fig. 1. The hammer head indicates approximately the base of the laterite at that spot.

Fig. 3.—Closeup of northerly face showing laterite over mottled clay. It is in this face, near the right side of this view that the laterite extends down along a joint-plane into the clay horizon.

Plate I.

Fig. 1

Fig. 2.

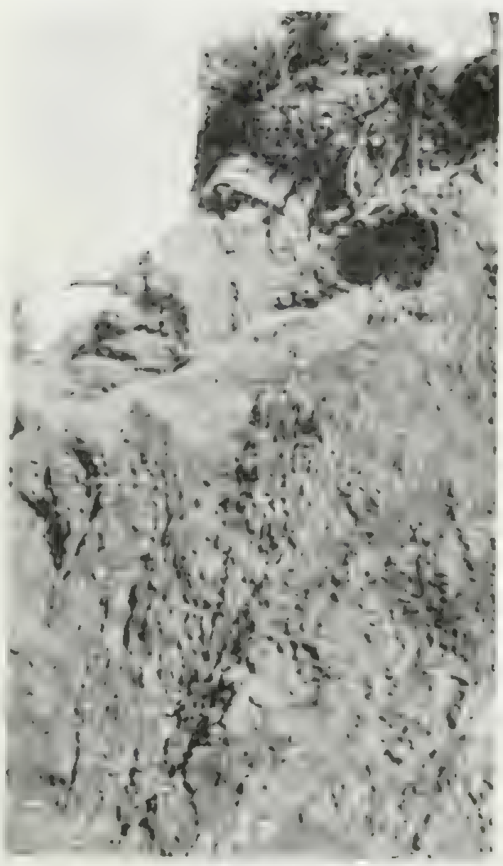

Fig. 3

PLATE II.

Photomicrographs.

Fig. 1.—Quartz-dolerite from which the laterite developed. (Ordinary light, 20x).

Fig. 2.—Primary laterite showing relict structure. (Ordinary light, 20x).

Fig. 3.—Same field between crossed nicols.

Fig. 4.—Laterite specimen taken from middle of stratum showing light coloured, general y isotropic, spherical bodies which appear to characterise the more aluminous material filling the solution channels and porous areas, but absent from the more ferruginous secondary material.

Fig. 5.—Same specimen as in Fig. 4 showing a solution channel filled with aluminous material and a second, formed later, filled with a more ferruginous mixture.

Plate II.

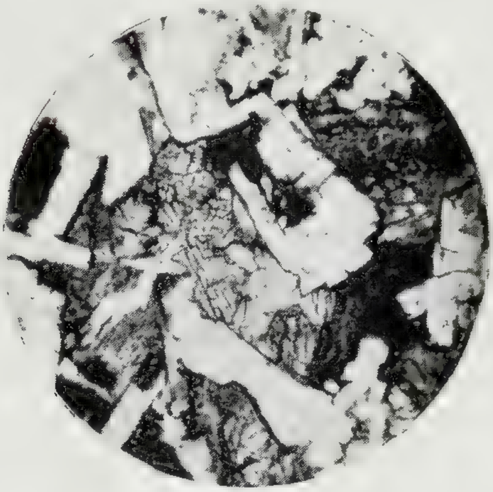

Fig. 1.

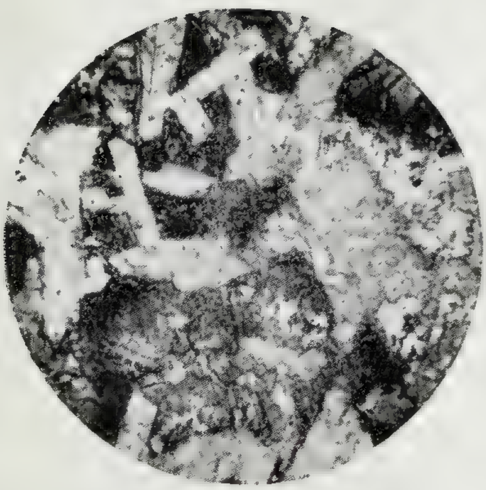

Fig. 2.

Fig. 3.

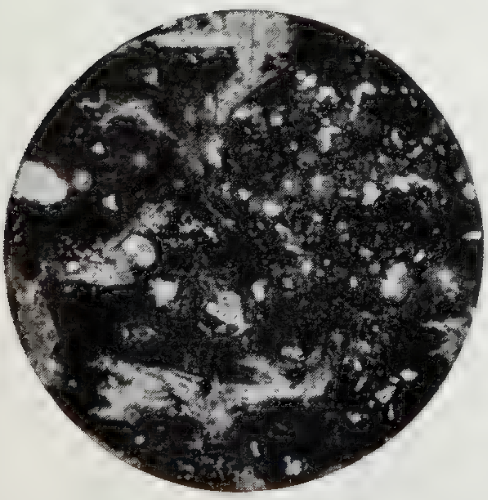

Fig. 4

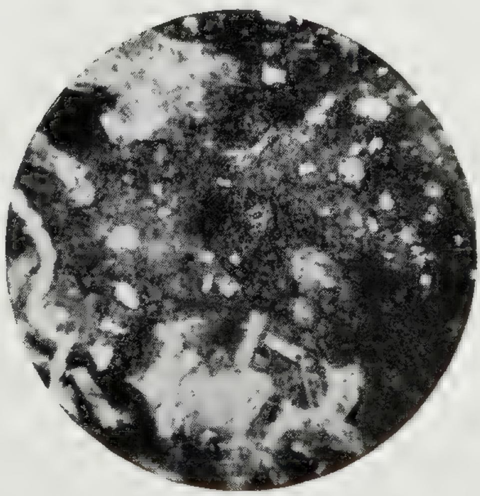

Fig. 5.

THE DEVELOPMENT OF OUR KNOWLEDGE OF THE MARSUPIALS OF WESTERN AUSTRALIA

PRESIDENTIAL ADDRESS, 1948.

By

L. GLAUERT, B.A.

Delivered 13th July, 1948.

In my address this evening I propose to deal with the development of our knowledge of the Marsupials of Western Australia from the distant days of the seventeenth century, when the Dutch navigators first landed on these shores, up to the present day.

As far as can be learnt from records available to us the Dutch under Pelsart were the first Europeans to study a marsupial at close quarters. During their enforced stay on the Abrolhos after the wreck of the " Batavia " in 1629, they not only used the local Tammar[1] as food but came to the conclusion that the young form and develop on the nipple, a fallacy which is dying hard, as even today there are bushmen in the out back who are still of the same opinion. Who can blame them when in the nineteenth century several learned ships doctors supported these views though it had been shown earlier by anatomists in London that such was not the case.

In 1658, Volckersen in his account of the voyage of the " Waeckende Boey " refers to Rottnest, which he did not name, stating they saw there " a wild cat resembling a civet-cat, but with browner hair,"[2] undoubtedly the Quokka which fortunately still occurs on the island. It was de Vlamingh, a visitor to the island in 1696, who mistaking the Quokka for " a kind of rat as big as a common cat," gave the island the name it still bears today.

Three years later Dampier landed on Dirk Hartog Island where he saw " a sort of Racoon different from those of the West Indies chiefly as to their legs ; for these have very short Fore-Legs, but go jumping upon them as the others do (and like them are very good meat)."[3] A little later when landing in Dampierland in search of water the men saw "a Rackoon or two"[4] probably the Yalva which was formerly plentiful among the sandhills near the shore.

In 1791, Vancouver saw a dead kangaroo at King George III. Sound and the following year the French zoologist Riche, a member of d'Entrecasteaux expedition in the " Recherche " and the " Esperance," when lost in the Esperance Bay district " encountered three kangaroos of the large species (*Didelphis gigantea*, Zimm.)[5].

At the beginning of the nineteenth century a French expedition visited these shores in the " Geographe " and the " Naturaliste."

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1 *Macropus (Thylogale) eugenii houtmanni* (Gould).
2 *Macropus (Setonix) brachyurus* (Quoy and Gaimard).
3 *Lagostrophus fasciatus* (Peron and Lesueur).
4 *Bettongia lesueur lesueur* Quoy and Gaimard.
5 *Macropus ocydromus* Gould.

The " Voyage de Decouverte aux Terres Australis " contains a detailed account of the animal met with in such numbers on Bernier Island[6] an English translation of this by W. B. Alexander is given in Volume 1 of the Journal of this Society.

During the voyage the island of Rottnest was also explored. Reference is made to this in the first volume where it is stated that two marsupials were found to be present[7]. This statement has led to a considerable amount of discussion, for when the English settlers occupied the island less than 30 years later only one species of the Quokka was found to be present. I have suggested[8] that the dimensions given (65 centimetres de hauteur) indicate an animal considerably larger than the Quokka but approximating the Tammar[9] which still exist on Garden Island where members of the expedition also went ashore.

Captain Mathew Flinders, who was surveying the coast, was at King George's Sound in January, 1802, where the kangaroo appeared to be numerous and of more than one species . . . " three of them seen by me bore a resemblance to the large kind which inhabits the forests of Port Jackson."[10] On Mondrain Island in the Recherche Archipelago they captured a few small kangaroos of a species different from any he had seen.[11]

In 1819, Captain P. P. King was off our northern shores where he reports that Kangaroos were seen in several places with Kangaroo Rats at Cambridge Gulf and Admiralty Gulfs. On his third visit in 1820 his botanist saw four individuals of a small species of kangaroo amongst the spinifex on the cliffs.[12] Near the water holes one of the crew saw a fifth Kangaroo of a grey colour and of a larger size than usual.[13] Small opossums were twice noted[14] the second " appeared to be the same animal that the colonists at Port Jackson call the Native Cat."[15]

The next year, King again visited the northern coast, this time in the " Bathurst," when the party ashore at Brunswick Bay saw many Kangaroo Rats and small Kangaroos[12] skipping about the rocks.

From January 20th to 26th the vessel was anchored at Dirk Hartog Island for minor repairs. Here Cunningham saw a small black Kangaroo which may have been the Banded Wallaby, *Lagostrophus fasciatus* so fully described by Peron.

The " Astrolabe " under Dumont D'Urville spent a fortnight at King George's Sound where Quoy and Gaimard found a dead wallaby[16] and captured several young bandicoots.[17]

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[6] *Lagostrophus fasciatus* (Peron and Lesueur).
[7] First Edition, 1807, pp. 188/9, Second Edition, 1824, pp. 368/9.
[8] *West Aust. Nat.*, Vol. I, No. 1, 1947, p. 22.
[9] *Macropus* (*Thylogale*) *eugenii derbianus* (Gray).
[10] *Macropus ocydromus* Gould, the Western Grey Kangaroo.
[11] Probably Hackett's Rock Wallaby. *Petrogale hacketii* Thomas.
[12] ? *Petrogale brachyotis brachyotis* Gould, or *Peradorcas concinna monastria* Thomas.
[13] ? Woodward's Kangaroo *Macropus robustus woodwardi* Thomas.
[14] *Trichosurus vulpecula arnhemensis* Collet.
[15] *Dasyurus* (*Satanellus*) *hallucatus exilis* Thomas.
[16] The type specimen of the Quokka, *Macropus* (*Setonix*) *brachyurus* (Quoy and Gaimard).
[17] *Isoodon obesulus fusciventer* (Gray) the type locality of which is King George's Sound.

Scott Nind who was the medical officer in the Penal Settlement at King George's Sound until October, 1829, mentions the following animals :—

The Grey Kangaroo, *Macropus ocydromus* Gould.

The Brush Kangaroo, *Macropus* (*Wallabia*) *irma* (Jourdan).

The Nailoit, *Potorous gilbertii* (Gould).

The Wahl, *Bettongia pencillata* (Waterhouse).

The Tammar, *Macropus* (*Thylogale*) *eugenii* (Desmarest).

The Quakur, *Macropus* (*Setonix*) *brachyurus* (Quoy and Gaimard).

The Comal, *Trichosurus vulpecula hypoleucus* (Wagner).

The Nworra, *Pseudocheirus occidentalis* Thomas.

With the foundation of the colony, the establishment of a seat of government on the Swan River, and the arrival of settlers who started to open up the country and showed an interest in the fauna and flora of their new homeland our knowledge grows apace. In 1830, Dale and Harvey penetrated 100 miles inland where they saw many kangaroos, chiefly of . . . "the larger kind which are properly called the Forest Kangaroo[18] and on October 17th killed a smaller one of another kind called the Mountain Kangaroo."[19]

The next year, Dale and another party including G. Fletcher Moore saw their first Numbat[20] south of Beverley on September 21st, actually capturing a specimen the following day. The animal was described and exhibited by G. R. Waterhouse at a meeting of the Zoological Society of London on July 12th, 1836. A second was placed before the Society on December 13th when James Reid introduced the first Dalgite[21] "an animal found beyond the mountains of Swan River in the district of York. They feed upon large maggots and the roots of trees and do considerable damage to the maize and potato crops by burrowing."

In December, 1837, George Grey and his party landed in Hanover Bay, remaining in the district until April exploring as much of the country as its ruggedness and the hostility of the natives would permit. Grey was an enthusiastic naturalist whose journals are full of observations dealing with the fauna and the aborigines of the colony. In the North he observed four species of kangaroo, "the large *Macropus giganteus*[22], two smaller kinds[23] one of which is the *Petrogale brachyotis* of Gould and a Kangaroo Rat[24], one species of opossum[25], a flying squirrel[26], two kinds of dogs . . ."

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18 *Macropus ocydromus* Gould.
19 *Petrogale lateralis* Gould.
20 *Myrmecobius fasciatus* Waterhouse.
21 *Macrotis lagotis* Reid.
22 *Macropus* (*Osphranter*) *robustus woodwardi* Thomas.
23 *Onychogalea unguifera* (Gould) *fide* Gray in Grey, p. 402.
24 *Bettongia lesueur lesueur* (Quoy and Gaimard), this species was common at Roebuck Bay and as Grey was familiar with the animal at "Swan River" we may regard his identification as correct.
25 *Trichosurus vulpecula arnhemensis* Collet.
26 *Petaurus breviceps* Waterhouse.

In the appendix, Gray gives a list of the marsupials known from Western Australia in which the following are given as occurring at Swan River :—

Phascogale murina ...	*Sminthopsis murina* Waterhouse
**Ph. leucogaster* ...	*Phascogale* (*Antechinus*) *flavipes leucogaster* (Gray)
**Myrmecobius fasciatus* Waterhouse	
**Perameles fusciventer*	*Isoodon obesulus fusciventer* (Gray)
**P. lagotis*	*Macrotis lagotis* Reid
Phalangista vulpina	*Trichosurus vulpecula hypoleucus* Wagner
Hepoona cookii	*Pseudocheirus occidentalis* Thomas
**Macropus lunatus*	*Onychogalea lunata* (Gould)
**Halmaturus manicatus*	*Macropus* (*Wallabia*) *irma* (Jourdan)
**H. brachyurus*	*Macropus* (*Setonix*) *brachyurus* (Quoy & Gaimard)
H. Derbianus obscurior	*Macropus* (*Thylogale*) *eugenii derbianus* (Gray)
**Petrogale lateralis* Gould	
**Hypsiprymus gilbertii*	*Potorous gilbertii* (Gould)
**Bettongia ogilbii*	*Bettongia pencillata ogilbyi* (Waterhouse)

of which those marked "*" were considerd to be "peculiar to the Western Australian district."

To this list we must add *Bettongia graii* said to have come from South Australia (Port Lincoln) but which we know, from G. R. Waterhouse's "Mar supialia," a volume in Jardine's Natural History, was at that time represented only by Gould's type and a young skin, both collected near Northam.[27]

This work by Waterhouse though undated was published in August, 1841, before Grey's journals were made available to the public. The introduction to the volume contains, on page 66, interesting notes by Dr. Collie on a foetal Kangaroo, probably from Garden Island.

"Mr. Collie describes a young of a species of Kangaroo (probably that described in this work as *derbianus*), which he saw at Garden Island or Buache, W.A., as being "nearly the size of the middle joint of one's little finger, its integuments of a flesh colour, and so transparent as to permit the higher coloured vessels and viscera to shine through them." This little foetus Mr. Collie detached from the nipple, and shortly afterwards placed the extremity of the teat close to its mouth, and having held it there for a short time without perceiving any decided effort on the part of the young animal to regain its hold allowed the pouch to close. An hour afterwards the young was observed still unattached, but in two hours it had hold of the teat and was actively employed sucking it."

On page 185 he describes *Hypsiprymnus ogilbyi* (Gould *ms*). from Swan River (York), the western form of *Bettongia pencillata* and among animals from Western Australia includes *P. bougainvillii*, overlooked by Gray whose *Bettongia lesueur harveyi* was not described until the following year. He also transfers *H. Graii* (type locality Northam) from South Australia.

[27] *loc. cit.*, p. 191.

In February, 1837, H.M. Sloop " Beagle " was commissioned to undertake a survey of the N.W. coast of Australia at first under Commander Wickham and later, March, 1841, under Captain J. Lort Stokes who completed the task and published in 1846 an interesting and extensive account of the six years' work. On the 15th November the vessel made Rottnest Island and soon afteranchored at Fremantle. Owing to the Captain's illness the vessel remained at the Swan River, the time being spent surveying the dangers which surround Rottnest Island " as well as those which lie between its shores and the coast " ; this survey of great importance to the interests of shipping in these waters was completed on subsequent visits. On 4th January, the vessel left for the north, at the end of the month they landed in northern Dampierland where, near Point Swan, they shot a nail-tailed Kangaroo[28] and " saw some very large red or cinnamon-coloured Kangaroos but never got near enough to secure one.[29]

When exploring the eastern shore of King Sound, Stokes met a number of " Rock Kangaroos " " bounding with defiance of pursuit." The same species was again seen at Port Osborne several days later and at Collier Bay on 12th April.[30]

During April and May, 1840, the " Beagle " was engaged in surveying the Abrolhos when the names East and West Wallabi were given to the islands on which the animals occur. Stokes remarks " the reader will obtain a good idea of the numbers in which these animals were found when I state that on one day within four hours I shot 36, and that between three guns we killed 76 . . . . The species has been described, from a specimen we obtained, as *Halmaturus Houtmanni*, it is distinct from *Halmaturus Derbyanus*[31], found on most of the islands on the southern parts of the Continent."

This material together with some from the north, resulted in an extensive account of the method of reproduction among the Macropods by the ship's surgeon Benjamin Bynoe.[32]

The " Beagle " then proceeded north where on Depuch Island Stokes knocked over a small Kangaroo on the summit of the island. He describes it fully adding that " Mr. Gould has figured an animal very like this I have described as *Petrogale lateralis* from a specimen he sometime afterwards got from Western Australia, but he has not noticed the beautiful Kangaroo from Depuch Island."

Later Barrow Island was visited and there they discovered a new kind of Kangaroo and Wallaby, the former was characterised as *Osphranter* (?) *isabellinus*[33] and the latter also new to science, received the name of *Lagorchestes conspicillatus* because of the pale ring around the eyes. Similar animals were found later on Tremouille and Hermite in the Montebello group. Stokes remarks that the description was based upon a specimen from Tremouille Island, but Gould gives Barrow Island as the type locality[34].

28 *Onychogalea unguifera* Gould.
29 Most probably *Macropus (Osphranter) robustus woodwardi* (Thomas).
30 *Petrogale brachyotis* Gould.
31 *Macropus eugenii derbianus* Gray.
32 Stokes' " Discoveries in Australia," Vol. 2, p. 156 *et seq.*
33 *Osphranter isabellinus* Gould., *Proc. Zool. Soc., Lond.*, 1841, p. 81.
34 *Proc. Zool. Soc., Lond.*, 1841, p. 82 (1842). This is confirmed by Gray in his list of 1843 and by Oldfield Thomas in the B.M. Catalogue of Marsupials (1888), p. 81. Specimen 41, 10, 12, 7.

In the meantime professional collectors had not been idle for towards the end of 1838 Dr. Ludwig Preiss, a German who had been financed by the Russian and Prussian governments, began to gather botanical and zoological material. He was an assiduous collector as is shown by a letter he wrote to the Governor on October 11th, 1839, offering his collections for a sum of money and a grant of land.

His material included about 15,000 insects, 150 species of shells, about 600 birds, 32 species of reptiles, 8 of frogs, 23 of fish and no less than 24 species of mammals each species represented by several specimens, among them the following marsupials :—

Dasyurus maugei Geof.	*Dasyurinus geoffroii fortis* Thomos
Perameles nasuta Geof.	*Isoodon obesulus fusciventer* (Gray)
Phalangista cookii Cuv.	*Pseudocheirus occidentalis* Thomas
Phalangista sp. n.	?
Petaurus two species	?
Macropus minor Shaw	*Potorous platyops* (Gould)
Macropus giganteus Shaw	*Macropus ocydromus* Gould
Macropus elegans	*Macropus* (*Wallabia*) *irma* Jourdan
Macropus rufogriseus Less	?
Macropus thetidis Less	*Macropus* (*Thylogale*) *eugenii* Desm.
Numbat	*Myrmecobius fasciatus* Waterhouse.
Dalgeit	*Macrotis lagotis Reid.*

At the same time he must have had ample funds as we learn from Gilbert that he was offering higher prices for specimens than Gilbert was prepared to pay. It is therefore not surprising that before his departure for London on January 8th, 1842, he should have amassed 200,000 plants, 200 species of insects, 181 species of birds and from 60 to 80 species of reptiles in addition to mammals and fishes, the number of which is not given in the information kindly supplied by Major H. M. Whittell. It is most unfortunate that the collections were dispersed commercially before reports upon the material were published. We know, however, that he obtained the types, a male and a female, of our Grey Kangaroo, *Macropus ocydromus* Gould, somewhere in Swan River[35], the co-types of *Lagorchestes-*(*Lagostrophus*) *albipilis* Gould, at Wongan Hills and York[36] and perhaps the type of *Phascogale apicalis* Gray, which had been purchased by the British Museum from J. G. W. Brandt of Hamburg in 1842.

Preiss worked principally in the country around Perth but he visited "the islands" and went inland to the Victoria District, the Wongan Hills, York, and along the track south from that centre to King George's Sound. The country around Albany was explored as far east as Mt. Manypeak and Cape Riche, and inland to the Gordon and Mt. Barker. He traversed the Albany road direct from Perth and was familiar with the coastal plain as is indicated by material obtained at Serpentine, the Murray, Port Leschenault, the Preston and the Vasse.

[35] Oldfield Thomas, *op. cit.*, 1888, p. 18.
[36] Oldfield Thomas, *op. cit.*, 1888, p. 102.

In a letter to Hooker published in the Journal of Botany, Vol. 2, 1840, James Drummond, the Colonial Botanist, describes a visit to Guangan[37] and the Salt River. He remarks that Kangaroos[38] were seen in hundreds on these sandy plains, adding that there were nine species at Swan River. "The animal called the Dolgitch[39] burrows in the ground, the Burdit[40] burrows in the ground or lives in holes in the rocks and the Manang[41], a small kind of Kangaroo, has a horny substance like a claw on the point of its tail."

John Gilbert who accompanied Drummond on some of his trips spent many months in this Colony collecting mammals, birds, reptiles and insects for John Gould. By a piece of good fortune Mr. A. H. Chisholm on a recent visit to England[42] was able to secure letters and other documents connected with these worthies, among which were lists of specimens forwarded to London by Gilbert.

Copies of these have been kindly supplied to me by Major H. M. Whittell. By the "Shepherd" which left here on January 1st, 1840, were sent the following Marsupials :—

2 Dalgytes	*Macrotis lagotis* Reid.
2 Native Cats	*Dasyurinus geoffroii fortis* (Thomas)
1 Opossum	*Trichosurus vulpecula* (Kerr)
2 Nombats	*Myrmecobius fasciatus* Waterhouse
1 Kangaroo Rat	*Bettongia pencillata ogilbyi* (Waterhouse)
1 large-eared Kangaroo Rat....	? *Choeropus ecaudatus occidentalis* (Gould)
1 Rock Kangaroo	*Petrogale lateralis* Gould
1 Burrowing Kangaroo Rat	*Bettongia lesueur graii* (Gould)
1 Wallaby	?

In December, 1843, the "Napoleon" left with a much richer cargo, including the following marsupials :—

4 *Macropus ocydromus*	
3 *Halmaturus manicatus*	*Macropus* (*Wallabia*) *irma* (Jourdan)
11 *Myrmecobius fasciatus*	
12 *Halmaturus Binoe*	*Macropus* (*Thylogale*) *eugenii houtmanni* (Gould)
2 *Bettongia ogilbyi*	*Bettongia pencillata ogilbyi* (Waterhouse)
12 *Halmaturus* (Damas)	*Macropus* (*Thylogale*) *eugenii derbianus* (Gray)
4 *Dasyurus viverrinus*	*Dasyurinus geoffroii fortis* (Thomas)
4 *Hypsiprymnus Gilbertii*	*Potorous gilbertii* (Gould)
2 *Halmaturus* ?	
4 *Macropus* (nail-tailed)	*Onychogalea lunata* (Gould)
1 *Phalangista vulpina*	*Trichosurus vulpecula hypoleucus* (Wagner)
4 *Perameles* (Mala)	*Perameles myosura* (Wagner)

37 ? Wongan Hills District, where Gilbert later obtained his first Gnow. *Leipoa ocellata* Gould.
38 *Macropus ocydromus* Gould.
39 *Macrotis lagotis* Reid.
40 *Bettongia lesueur graii* (Gould.).
41 *Onychogalea lunata* (Gould.).
42 Chisholm, *The Emu*, Vol. XXXIX, 1940, Whittell, *The Emu*, Vol. XII., 1941.

2	*Phascogale* ?	
16	*Phascogale* ?	
6	*Phascogale* ?	
4	*Tarsipes spencerae*	*Tarsipes spenserae* (Gray)
7	*Perameles fusciventer*	*Isoodon obesulus fusciventer* (Gray)
13	*Petrogale lateralis* Gould, 1842	
19	*Bettongia Grayii*	*Bettongia lesueur graii* (Gould)
6	*Lagorchestes albipilis*	*Lagostrophus fasciatus albipilis* (Gould)
1	*Hypsiprymnus*	
8	*Perameles lagotis*	*Macrotis lagotis* Reid
3	*Lagorchestes* ? (Woorup)....	*Lagorchestes hirsutus hirsutus* (Gould)
4	*Hepoona Cookii*	*Pseudocheirus occidentalis* (Thomas)
3	*Phascogale pencillata*	*Phascogale tapoatafa* (Meyer)
23	*Phascogale* ?	
1	*Phascogale* ?	
2	*Chasopus* (*sic*)	*Chaeropus ecaudatus occidentalis* (Gould)
3	*Dromicius glirformis*	*Cercartetus concinnus* (Gould)
1	*Phascogale* ?	

The number of scientific names used by Gilbert in this second list are an indication of the advances made during the four years between the two consignments. Gilbert visited the Abrolhos, the islands off Fremantle, the South West from New Norcia (Moore's River) southwards and inland to the Gordon Plains and Wongan Hills district.

On some of these expeditions he was accompanied by Johnson Drummond, son of the Colonial Botanist, who collected mammals and birds for Gould and in return received copies of Gould's Monographs of the Macropodidae[43] and the Birds of Australia. These are now in the possession of a relative, Mrs. J. M. Drummond of Peppermint Grove.

Gilbert collected the types of a number of W.A. mammals, descriptions of which mostly appeared in the Annals and Magazine of Natural History and the Proceedings of the Zoological Society of London.

They include :—

Antechinus flavipes leucogaster (Gray) ...	Canning River.
Phascogale calura Gould	Williams River
Sminthopsis c. crassicaudata (Gould)	Williams River.
Isoodon obesulus fusciventer (Gray)	King George's Sound.
Sminthopsis murina fuliginosa (Gould)	River Avon.
Chaeropus ecaudatus occidentalis Gould .	Boorda, Kirltana W.A.[44].
Cercartetus concinnus (Gould) . .	Swan River.
Pseudocheirus occidentalis Thomas .	King George's Sound.
Bettongia pencillata ogilbyi (Gould m.s.) (Waterhouse)	York.
Potorous gilbertii (Gould) .	King George's Sound.
Potorous platyops (Gould) . . .	Walyema Swamp, 40 miles N.E. of Northam
Lagorchestes hirsutus hirsutus (Gould) . .	York District.
Onychogalea lunata (Gould)	Swan River.
Petrogale lateralis Gould	Swan River.

which provide a lasting tribute to John Gilbert's energy and ability as a collector.

[43] This work, which was not completed, contained descriptions of figures of two Western Australian species, *Hypsiprymnus Gilbertii* from King George's Sound in Part 1 (1841), and *Petrogale lateralis* from Swan River in Part 2 (1842): both the types were collected by Gilbert.
[44] Thomas, O., *Brit. Mus. Cat.*: Mars and Monotr: (1888), p. 252.

Gilbert paid two visits to Western Australia, the first extending from March, 1839 to February, 1840, and the second from July, 1842 to December, 1843.

The year 1846, saw the completion of the "The Natural History of the Mammalia, Vol. 1, Marsupiata or Pouched Animals," by G. R. Waterhouse, which had appeared in monthly parts. The author carefully examined all the material available, he added one species to the list[48], which increased the number of Western Australian forms to 36. On the other hand *Macropus melanops*, and *M. ocydromus* are regarded as synonyms of *M. giganteus*, Gould's *Macropus* (*Lagorchestes*) *albipilis* from Moore River is united with Peron and Lesueur's *fasciatus* from Sharks Bay and the *Halmaturus binoe* of Gould from Port Essington reduced to a synonym because it " so perfectly resembles his *Halmaturus agilis* in all respects excepting size, that I cannot regard it as a distinct species . . . . . . in size this animal nearly agrees with the *Halmaturus derbianus*.

Gould later admitted that he had been mistaken and agreed with Waterhouse that the sepcimen was a young *Halmaturus agilis*.[49]

Waterhouse correctly relegated *Macropus* (*Halmaturus*) *manicatus* of Gould to the synonomy of Jourdan's *M.* (*H.*) *irma*. Gray's *H. brevicaudatus* to that of Quoy and Gaimard's *M.* (*H.*) *brachyurus*[50], but he erred in connection with *Tarsipes rostratus* which has not priority over Gray's *Tarsipes spenserae* published three months earlier although some three months after the specimen described by Gervais and Verreaux had been exhibited at a meeting of the Zoological Society of London.

The Tammars presented a difficulty which was solved by regarding Gould's *Halmaturus dama* and *H. gracilis* from the western mainland as synonyms of Desmarest's *Kangurus eugenii* from the Nuyts Archipelaga of South Australia, whilst *Halmaturus derbianus* based on a specimen in Lord Derby's menagerie later presented to the Zoological Society, was considered to be a distinct species " strictly confined to the islands off the west coast " though Gould had stated that this occurred on Kangaroo Island and had been informed that it " inhabited Rottnest and Garden Island." Geographically this seems unsatisfactory as several later workers have realised, each supplying his own solution.

The Western Ringtail is regarded by Waterhouse as identical with the eastern *Phalangista* (*Pseudocheirus*) *cookii* although he remarks that the Swan River specimens are very dark.

We have seen that in December, 1843, Gilbert forwarded to Gould two specimens of " *Chasopus* " undoubtedly the *Chaeropus* on which Gould based his *Chaeropus occidentalis*. Two *Chaeropus* were in the collection of the British Museum when Waterhouse wrote, one from South Australia presented by George Gray and the second " from the Swan River district, where, according to Mr. Gould, the species is confined to the interior of the country." Waterhouse does not compare the specimens nor does he mention Gould's name *occidentalis*, given to the Swan River specimen in the previous year.

45 Mammals of Australia, Vol. 22, text to plates 24 and 25.
46 Catalogue of Marsupalia and Monotremata, p. 44 (1888).
47 A check list of the Mammals recorded from Australia (1834), *Aust. Mus. Mem.*, VI.
48 *Phalangista* (*Dromicia*) *neillii*, from King George's Sound. Actually a miniature male *Cercartetus concinnus* (Gould.)
49 *Wallabia agilis* (Gould.)
50 *Setonix brachyurus* (Quoy and Gaimard).

At the end of the Volume are lists showing the distribution of the Marsupiata in Australia.

The section "North Australia" contains several forms first collected within the boundaries of this state. From the lists of Western Australian species "*Macropus eugenii*" is omitted although earlier in the text *M. dama* and *M. gracilis* both with type locality in Western Australia, are relegated to its synonymy. There is also no mention of *Dasyurus geoffroii* and *Chaeropus ecaudatus*, which we have seen were included in the second list of specimens sent to Gould by Gilbert in 1843. On the other hand the list is increased by including both *Macropus giganteus* and *Macropus giganteus ocydromus* together with *Phalangista vulpina* and *Phalangista vulpina xanthopus* Ogilby in spite of the fact that on page 295 it is stated that the exact part of the Continent inhabited by this form is unknown. *Phalangista neillii* of course appears in the list as independent of the older *Phalangista concinna*.

From June to September, 1854, Assistant Surveyor R. Austin conducted investigations into the nature of the country around Lake Cowcowing and northwards to Lake Austin, from which point he turned in a westerly direction endeavouring to reach the mouth of the Gascoyne River but was forced by drought conditions to return to the Murchison River and make for the Geraldine Mine. In his report the surveyor noted many of the animals seen, some of which were reported on by W. A. Sanford in an appendix to the Report, the most noteworthy discovery being the presence of the Red Kangaroo on the Murchison.

The Grey Kangaroo, called the common Kangaroo, was met with at Goomalling, Koomberkine Lake, Ejanding, and in the Cowcowing district. The Red Kangaroo occurred in varying numbers around Mt. Magnet, west of Mt. Farmer and in the country of the Murchison River Valley. Of the first specimen shot, Austin writes "These animals are not all of them red ; some are of a blue or slate colour with white throats and breasts, and tan marks on each side of the face. I have seen them both, bucks and does, varying thus in colour, herding and feeding together."

This description is of interest as the general impression current today is that only the does show the blue colouration and in my experience of Murchison animals which I have shot and examined in 1922, this certainly seemed to be the case. On the other hand on the Gascoyne a few years later I saw mixed flocks as described by Austin, the individuals, males, females and young being either red or blue in approximately equal proportion in some of the herds.

A male and a female were preserved by Austin, being brought safely to Perth, in spite of the dangers and privations of the western journey, and later presented to the British Museum where they are still in the collection. The presence of the animal in Western Australia was so unexpected that as late as 1888, Oldfield Thomas in the British Museum Catalogue doubted the accuracy of the statement that Austin's skins had been obtained in this colony.

Near the Roderick River, a tributary of the Murchison, Austin "fired at, and missed two moderate sized black Kangaroos" whose identity is uncertain and in the same district, at Mt. Welcome, killed Rock Kangaroos[51] of the species

[51] *Petrogale lateralis* Gould.

previously met with and shot at Waddouring, and a few miles west of Mt. Farmer. Warrungs[52] abounded in cypress thickets at Wandanning, east of Lake Moore, and in the Mt. Magnet district, Kangaroo-Rats[53] were noticed at Koomberkine and north of Dijoin (?Datjoin) and possums at Goomalling where they are common—hence the name from Kumarl, a possum—and Wandanning ; whilst a large quantity of possum fur was found at a deserted natives' camp 15½ miles north of " Dijoin." Although Dalgites were not seen, their tracks and burrows were noticed near Recuit Flats in the Mt. Magnet district.

The letter from W. A. Sanford, printed on pages VIII and IX deals with the mammalian and avian fauna and is based upon skins submitted and adequate descriptions. The list includes :—

Osphranter rufus, Great Red Kangaroo
Lagorchestes hirsutus, Rufous Hare Wallaby

based upon specimens, as well as—

Chaeropus castanotis, Chestnut-eared Hog's-foot
Onychogalea luna'a, Lunated nail-tailed Kangaroo or Worung.

Although the *Chaeropus* was said to have been met with in large numbers, to have been so common as not to deserve mention in the body of the report, it has long disappeared from the greater part of Western Australia. It was not seen by Tunney, who traversed much of the State 50 years ago collecting for the Museum, and it is not represented in the Museum's collection.

Although out of place in this paper, I cannot refrain from mentioning that the rare False Vampire Bat, *Macroderma gigas* (Dobson) was seen by Austin in a cave on Mt. Kenneth. Three individuals " the size of a common pidgeon and brilliantly white " flew out of a crevice in the overhanging rocks and escaped.

John Gould's sumptuous work on the Mammals of Australia, commenced in 1845, was completed in 1863. It contains excellent lifelike representations though often on a heroic scale of the species dealt with. Notes on habits and distribution are given and, in connection with most Western Australian forms, the names by which the animals are known to the natives (Gilbert in his letters often referred to his efforts to obtain this information). As regards distribution it must be remembered that " interior of Swan River " referred to the country near York, the Avon River Valley, and so on, and not to the far interior as we know it today. Contemporary maps show how little was known at that time, and even a decade or two later, of the vast tract of country included within the boundaries of Western Australia.

In the late sixties, George Masters of Sydney made two collecting trips to South Western Australia, the first to King George's Sound during the months of January to April, 1866, and the second extending over the Spring and Summer of 1868–1869 (22nd September to 1st April). This was again to the King George's Sound area though we know from material in the British Museum that he went as far afield as Pallinup River (Salt River).

The lists of specimens obtained include many of interest and rarity.

[52] *Onychogatea lunata* (Gould).
[53] *Bettongia lesueur graii* (Gould).

Mammals collected by George Masters "in the vicinity of King George's Sound during the months of January, February, March, April, 1866.[54]

	Skeletons.	Skulls.	Skins.	In Spirit.
Macropus ocydromus	....	1	....	....
Halmaturus manicatus	....	....	1	2 young
Halmaturus derbianus	....	1	6	6 young
Halmaturus brachyurus	....	1	18	5 young
Lagorchestes fasciatus	....	....	1	....
Onychogale lunata	....	....	6	....
Bettongia campestris	1	1	3	....
Bettongia ogilbyi	....	....	2	....
Hypsiprymnus gilberti	....	....	5	3 young
Hypsiprymnus platyops	....	....	1	....
Peragalea lagotis	....	....	1	....
Pérameles obesula	....	....	4	2 adults 4 young
Phalangista viverrina	....	1	7	2 young
Dasyurus geoffroyi	....	....	1	....
Tarsipes rostratus	....	....	....	28 adults 2 young
Antechinus fuliginosus	....	....	....	54 adults
Antechinus leucogastor	....	....	....	4 adults

Mammals collected in Western Australia by George Masters from 22nd September, 1868, to 1st April, 1869.[55]

Pencil note "King George's Sound and Salt River."

	Skeletons.	Skulls.	Skins.	In Spirit.
Myrmecobius fasciatus	....	....	1	1 adult
Perameles myosurus	....	7	2	20 adults and young
Perameles obesula	....	2	2	4 adults and young
Phalangista vulpina	....	1	2	1 young
Phalangista viverrina	1	1	3	4 young
Phascogale penicillata	....	1	....	1 adult
Antechinus leucogastor	....	2	....	10 adults and young
Antechinus fuliginosus	....	....	....	11 adults
Antechinus apicalis	....	....	....	1 adult
Dasyurus geoffroyi	....	1	2	.
Macropus ocydromus	1	9	5	1 young
Halmaturus manicatus	1	3	5	....
Halmaturus derbianus	....	1	8	1 young
Halmaturus brachyurus	6	6	8	8 young
Onychogale lunata	1	1	3	1 young
Lagorchestes fasciatus	1	....	5	....
Bettongia ogilbyi	1	6	3	2 young
Bettongia graii	....	1	2	.
Hypsiprymnus gilbertii	1	....	....	1 young
Hypsiprymnus platyops	....	....	1	2 adults

[54] Copied from list of Masters' specimens (Australian Museum). List lent by Major Whittell.
[55] Copied from list of Masters' specimens (Australian Museum). List lent by Major Whittell.

The Catalogue of the Marsupialia and Monotremata in the collection of the British Museum (Natural History) by Oldfield Thomas of 1888, contains the description of the Western Ringtail *Pseudochirus occidentalis* now for the first time separated from the Eastern *Ps. peregrinus* with which it had previously been identified, although as we have seen its darker colouration had been noted. A number of the species erected by Gould and others are reduced to the synonymy, *M. ocydromus* Gould is considered to be identical with *M. giganteus* (Zimm.) but *M. melanops* Gould is given sub-specific rank. *M. manicatus* Gould is placed in the synonymy of *M. irma* Jourd, *H. binoe* Gould in that of *M. agilis* Gould and the Tammar, *M. eugenii* Desm. given the following long list *H. derbianus* Gray from Swan River, *H. emiliae* Gray (n.n.) from the Abrolhos. *H. houtmanni* Gould from East Wallabi Island, *H. dama* Gould Moore's River, and *H. gracilis* Gould from Walyema Swamp, N.E. of Northam. The *H.* (*T*) *brevicaudatus* of Gray is antedated by the *M. brachyurus* of Q. & G. *L. leichardti* Gould is considered a subspecies of *L. conspicillatus* Gould, but similar rank is not allowed to *L. albipilis* Gould which is entered in the synonymy of *Lagostrophus fasciatus* Per & Less., a decision which Thomas himself altered in later years. The western form *Bettongia ogilbyi* (Gould) Waterhouse was merged into the eastern *B. penicillata* Gray and *B. Graii* Gould into *B. lesueuri*. Among the Phalangeridae, the priority of *Tarsipes spenserae* Gray over *T. rostratus* Gerv. & Verr. is not yet recognised. *Dromicia neilli* Waterhouse is merged in *D. concinna* Gould, *Perameles fusciventer* Gray in *P. obesula* (Shaw), and *P. arenaria* Gould in the *P. bougainvillei* of Quoy and Gaimard. For the pig-footed bandicoot *Chaeropus* the name *ecaudatus* Ogilby is incorrectly disallowed because it was based upon a mutilated specimen and *castanotis* Gray substituted, and the name *occidentalis* suggested by Gould for the western representative disallowed. The type locality of this form " inland from York " is given as " Boorda Kirltana W.A." by Thomas. Gray's *leucogaster* for the western *Ph. flavipes* Waterhouse and *fuliginosus* Gould for the western *Sm. murina* Waterhouse reduced to the synonymy are restored by later workers.[56]

Finally the *Sminthopsis* collected by W. W. Froggatt in the " Pindan " scrub bordering King Sound near Derby and described as *Antechinus* (*Podabrus*) *froggatti* by E. R. Ramsay[57] was merged into the widespread species *Sminthopsis crassicaudata* Gould from which it was reinstated as *Sminthopsis froggatti* by Troughton in 1932[58].

Ramsay's *Perameles auratus*[59] was, however, allowed to stand as a good species.

We now turn to activities in Australia and the work of collectors in this State.

In May, 1894, K. Dahl of Christiania landed in South Australia to commence a collecting expedition to the Northern Territory and West Kimberley, which was to extend over the next 21 months. Much of this time was spent in the Territory but on October 10th, 1895, the party landed at Roebuck Bay to spend four exciting months in Dampier Land.

They displayed the greatest energy and were well assisted by Mr. Male, the local agent of Messrs. Streeter, owners of Hill Station. The collections made " represented the higher mammals of North-Western Australia in a

[56] *e.g.*, Iredale and Troughton, 1934.
[57] *Proc. Linn. Soc., N.S.W.* (2), 1887, (1888), p. 552.
[58] *Rec. Aust. Mus.*, Vol. XVIII., No. 6, 1932, p. 352.
[59] *Op. cit.*, p. 551—Now *Isoodon* ; *uratus* (Ramsay).

quite exhaustive manner." Dahl knew that they contained some hitherto unkown animal forms, and he felt convinced that these exhaustive collections from a region little known or examined, would prove well worth the toil spent in their accumulation.

In the Roebuck Bay district, the following marsupials were obtained[60] :—

The Jungle Kangaroo	*Macropus agilis.*
The Yalva or Kangaroo Rat	*Bettongia lesueur.*
The Northern Nail Tailed Wallaby	*Onychogalea unguifera.*

The Northern Possum, *Trichosurus vulpecula arnhemensis* Collet, was made known to Science for the first time and the little Flying Squirrel, *Petaurus breviceps*, was added to the Western Australian list, being rather rare.

A species of Bandicoot presumed to be *Isoodon obesulus* but really *Isoodon auratus* Ramsay, the Golden Bandicoot, was obtained and a single Phascogale, the Warmbenger, *Phascogale tapoatafa pirata* Thomas, was seen.

About this time the late John T. Tunney began his long association with the Western Australian Museum as a collector, in the course of which he travelled thousands of miles in this State, and in the Northern Territory besides visiting a number of islands off our coasts. Although birds were his principal objective, he included numerous specimens of mammals in the Collections he made. He visited most of the localities made famous by John Gilbert and Dahl, but also broke much new ground. The Plans of his various tours were prepared by the late Bernard H. Woodward, F.G.S., C.M.Z.S., first Curator and then Director of the Western Australian Museum and Art Gallery, whose name is associated with two of Tunney's larger Kangaroos in the North. *Macropus robustus woodwardi* Thomas, from the Kimberley district and *Macropus bernardus* Thomas, from the South Alligator area of the Northern Territory.

Tunney rediscovered the *Osphranter isabellinus* of Gould first collected by Captain Stokes of the Beagle on Barrow Island in 1840. He also collected specimens of a number of animals which proved to be new to Science and were described by Oldfield Thomas, F.R.S., in various scientific publications. The list included *Macropus robustus cervinus* Thomas from Pindar on the Murchison, *Macropus robustus woodwardi* Thomas from the Grant Range, West Kimberley ; *Petrogale rothschildi* Thomas from the Cossack River ; *Petrogale hacketti* Thomas from Mondrain Island in the Recherche Archipelago ; *Isoodon barrowensis* Thomas from Barrow Island. To these Dr. Ernst Schwarz, added *Macropus robustus rubens* and *Macropus rufus pallidus* in 1910[61].

Subsequent additions to the fauna are few, but much has been learnt concerning the distribution of species and forms. In December, 1901, Mr. A. C. Blyth—Not Bligh as stated by Waite—presented to the Museum two small marsupials which he had caught " in the Pilbarra District." Other specimens were taken to Sydney where Mr. Bligh placed them in the care of Mr. Waite for observation. These three animals subsequently escaped and were never seen again. Later the two specimens left in Perth were forwarded to Sydney for examination where they were found to be new to science, and received the name of *Phascogale blythi*[62] Waite.

[60] R. Collet, *Proc. Zool. Soc., Lond.*, 1897, p. 317.
[61] *Novitates Zool.*, XVII., 1910, pp. 51 and 53.
[62] As this is a *lapsus calami* the name should be altered in accordance with International Rules Article 19, to *Ph. blighi-Dasycercus blighi.* See G. C. Shortridge *Proc. Zool. Soc. Lond.*, 1909 (1910). p. 804.

In 1906 the Zoological Gardens in Frankfurt A.M., received specimens of *Macropus rufus* (Desm.) from the Murchison district which were examined by Dr. P. Cahn and considered to represent a distinct form to which the name *Macropus rufus occidentalis* was given[63], although it is now rightly considered to be identical with Rothschild's *Macropus rufus dissimulatus*[64] and is accordingly placed in the synonymy of this form by Iredale and Troughton.

In 1904 and 1905, Mr. G. C. Shortridge collected in Southern W.A. for the British Museum (Natural History), the expenses being defrayed by Mr. W.E. Balston. The districts visited were among those made famous by the work of John Gilbert—Beverley, York, Northam, Toodyay and Wongan Hills—as well as new ground on the King River near Albany, Wagin, Southern Cross, Kalgoorlie and Laverton. Extensive series of most animals were obtained, although a number of forms generally considered common or characteristic, were found to be either rare or absent. Later another collection was made in regions where the fauna still persisted in its original state. Stockpool, east of Beverley, Dwaladine, east of Brookton, and Woyaline east of Pingelly and Dale River to the west of the Avon Valley, were visited with marked success. A further trip was made to Bernier Island in Shark Bay, where the bag consisted of the Wallabies *Bettongia lesueur lesueur* (Q. and G.), *Lagostrophus fasciatus fasciatus* (P. and L.), and *Lagorchestes hirsutus bernieri*[65] Thomas, the last a new form. An imperfect skull of the Bandicoot *Perameles bougainville* was the only evidence obtained of the presence of these marsupials. When examining this material, Thomas compared it with some obtained in that area by J. T. Tunney in 1899, and as a result the *Lagorchestes* from Dorre Island was considered to be distinct from its neighbours and given the name of *Lagorchestes hirsutus dorreae*[66]. A critical examination of the material obtained further south revealed that the *Lagostrophus* from the S.W., was distinct from that living in the Shark Bay area and so Gould's *albipilis* was revived as a sub-species. Good series were obtained representing species now either rare or extinct. Only one new form was described, the western *Dasyurus geoffroii* being separated from its eastern relative because it was "larger, the difference specially marked in male skulls," hence the name *fortis*[67].

An interesting addition to our marsupial fauna was recorded in No. 4 of the Journal of the W.A. Natural History Society by C. P. Conigrave's paper on the Marsupial Mole, *Notoryctes typhlops* Stirling. A specimen of this rare animal of the Eremaea obtained near Mt. Romilly where Col. Warburton's track crosses the Canning Stock Route was presented to the Museum by Mr. H. S. Trotman, second in command of the survey party.

Several further specimens have since reached the Museum, mostly from Wallal, one of these when sent to Oldfield Thomas, was made the type of a new species—*N. caurinus*[69] Thomas.

Another inhabitant of the arid North West, was described by Baldwin Spencer, 1908 as *Sminthopsis longicaudatus*[68], the habitat is given as West Australia only, but as we know that the collector, G. A. Keartland, was in the

[63] *Zool. Beob.*, XLVII., 1906, p. 361.
[64] *Novitates Zoologicae*, Vol. XII., 1905, p. 508.
[65] *Proc.: Zool. Soc. Lond.*, 1906 (1907), part 2, pp. 468 and 763, see p. 775.
[66] *Proc.: Zool. Soc. Lond.*, 1906 (1907), part 2, pp. 468 and 763, see p. 775.
An account of the geographical distribution of the species (with maps) appears in *Proc. Zool. Soc. Lond.*, 1909 (1910), p. 803.
[67] *Dasyurinus geoffroii fortis* (Thomas) *op. cit.*, p. 476.
[68] *Proc. Roy. Soc., Vic.*, (n.s.), 1908, p. 449.

In a contribution "The External Characters of *Thylacinus, Sarcophilus* and some Related Marsupials,"[76] R. I. Pocock subdivides the old genus *Dasyurus*, into four genera basing his opinion upon the structure of the feet, and in one case on the dentition as well. The type of the restricted *Dasyurusis viverrinus* Shaw, *Notoctonus*[77] has *geoffroii* Gould as its type and *Satanellus* is given *hallucatus* Gould.

About the same time there was published in London "The Wild Animals of Australia," by A. S. le Souef and H. Burrell with a chapter on the Bats by E. le G. Troughton. The authors describe all the forms recognised, often with notes on the habits, the nomenclature being that generally accepted at the time. It is still the most useful book available though in parts it is necessarily out of date.

In "Notes on Four Little-known Species of Kangaroo,"[78] A. S. Le Souef gives reasons for supporting the opinion expressed in a previous paper[79] why *M. melanops* Gould must be considered to be distinct from *M. giganteus* (Zimm.). *Macropus hagenbecki* Rothschild is also referred to, the statement being made that "the sexes are alike in coloration." On the other hand when Schwartz prepared his monograph in 1910 only an immature individual with the milk premolar still in position was available for study, the other older individual having been lost.[80]

The Government party under Surveyor Canning, engaged during 1930–31 in reconditioning the wells on the Canning Stock Route between Wiluna and Hall's Creek, was accompanied by the Museum Taxidermist, the late O. H. Lipfert, who made a fine general collection from practically unknown country. A number of marsupials were obtained including some interesting forms. *Dasyurinus geoffroii* (Gould) was found at Well 46, far north of its previously recorded range and of very special interest because the Pilbara District has a Dasyure closely related to, if not actually identical with, the *Satanellus hallucatus* (Gould) of the Kimberleys and Northern Territory. An *Antechinomys*, perhaps *A. lanigier* Gould, was caught near Sturt Creek, the first Western Australian specimen of the genus, and several *Sminthopsis* reminiscent of the *S. hirtipes* Thomas of Central Australia. The Northern Bandicoot, *Isoodon auratus* (Ramsay) was found as far south as Well 36, and the Northern Possum, *Trichosurus vulpecula arnhemensis* Thomas at Sturt Creek. The fauna of the Eremaea was represented by *Notoryctes caurinus* Thomas, *Lagorchestes hirsutus* Gould, and many *Dasycercus cristicauda* (Krefft)[81]. *Macrotis lagotis* (Reid) was also present.

In 1931, Surveyor H. L. Paine and the Government Geologist F. G. Forman undertook a venturesome journey eastwards to the South Australian border and, while in the country south of the 26th parallel and slightly east and west of the 126th meridian, made a small collection of Marsupials including single specimens of *Lagorchestes hirsutus* Gould, *Macrotis lagotis* Reid, *Isoodon auratus* (Ramsay), *Dasycercus cristicauda* (Krefft), *Sminthopsis hirtipes* Thomas, which a little earlier had been added to the W.A. list by Lipfert and a most interesting little Bandicoot, unfortunately immature, of the genus *Perameles*.

76 *Proc. Zool. Soc. Lond.*, 1926, p. 1037.
77 Antedated by *Dasyurinus* Matschie, 1916, *fide* Iredale and Troughton, 1934.
78 *Proc. Linn. Soc., N.S.W.*, 53, part 4, 1928, p. 397, text figs. A–D.
79 *Aust. Zool.*, Vol. 3, No. 4, 1923, p. 145.
80 This "species" is referred to here as some years ago the late A. Goerling of Marloo Station in the Murchison, told me that he had collected the animal "north of the Murchison" for Karl Hagenbeck of Hamburg, who sold it to Lord Rothschild.
81 The long series collected include *D. c. cristicauda* and *D. c. hillieri* Thomas, suggesting that the latter is merely a colour variation and not a sub-species or race, neither is it sexual nor seasonal.

Pilbara and the desert to the east and as the Museum possesses a specimen, M2394, of the same species from Pillendinnie (Marble Bar) we may assume the specimen came from that part of the State.

In 1908 and 1909 two small collections of Marsupials from the far north were purchased from a collector, J. P. Rogers. The first contained a Northern Spotted Native Cat, *Satanellus hallucatus*, which Oldfield Thomas found showed differences from the typical form prevalent in the Northern Territory and was therefore given the name *Dasyurus hallucatus exilis* Thomas[70]. In the second consignment, were skins of a Northern Hill Kangaroo from East Kimberley, which, because of certain characters, was differed from *Macropus robustus woodwardi* Thomas, from West Kimberly, was named *M. r. bracteator* Thomas[71], this sub-species is not recognised by Iredale and Troughton. At the Negri River, just inside the Western Australian border, Rogers also obtained a typical example of *Macropus antilopinus* Gould, originally collected at Port Essington by John Gilbert a century ago. A paper by Dr. S. Schwarz, which appeared in the Annals and Magazine of Natural History for February, 1910, contained the description of a new form of the Jungle Kangaroo, *Macropus agilis aurescens* Schwarz, from the Fitzroy River and the Grant Range in West Kimberley. In the Novitates Zoological Vol. XVII., published in the next month, this author contributed an important paper on the large Kangaroos and their geographical forms. This contains the original descriptions of *Macropus rufus pallidus* (type locality Shaw River), *Macropus robustus rubens* (type locality Box Soak) and the inference that Rothschild's *Macropus hagenbecki* of 1907[72] is a hybrid *Macropus rufus* X *M. robustus*, although this is not stated.

Dr. Mjoberg's Swedish Scientific Expedition arrived in Western Australia in 1910 and spent several months in the State chiefly in West Kimberley, but also in the South West between Perth and Albany. The marsupials obtained were :—

A young unidentified *Lagorchestes* and

The Organ Grinder Wallaby	*Onychogalea unguifera* (Gould)
Woodward's Kangaroo	*Macropus robustus woodwardi* Thomas
The Jungle Kangaroo	*Macropus agilis aurescens* Schwarz
The Dark Jungle Kangaroo	*Macropus agilis nigrescens.* Lonnb. n.s.sp. Type Loc. Broome.
Phascogale subtilissima, Lonnb.[73]	Type Loc. Near Noonkambah Station.

An outstanding addition to our Marsupial fauna to be published in our Journal was made by W. B. Alexander in a paper read on April 9th, 1918[74], describing a new species of marsupial of the sub-family Phalangerinae to which the name *Wyulda squamicaudata* was given. This animal is closely related both to *Trichosurus* and *Phalanger*. It appears to be more or less terrestrial in its habits in this manner recalling the *Petropseudes dahli* (Collet), of the Northern Territory.[75]

[69] *Notoryctes caurinus* Thomas *Ann. Mag. Nat. Hist.*, July, 1920, p. 111.
[70] *Satanellus hallucatus exilis* (Thomas), *Ann. Mag. Nat. Hist.* (8) III., 1909, p. 152.
[71] *Ann. Mag. Nat. Hist.* (8) VII., 1911, p. 609.
[72] *Novitates Zoological* 14, p. 333.
[73] *Kungl. Sv. Vet. Akad.* Haudl. III., No. 1, p. 9, now *Planigale subtilissima.*
[74] *Journ. Roy. Soc. W.A.*, Vol. IV., 1917–8 (1919), p. 31, pl. I.
[75] *Zool. Anzeiger* XVIII., No. 490, 1895, p. 464.

This resembles a young *Perameles bougainville* Q. & G. from Dorre Island in the Museum series, but seems to have longer and softer fur, a brighter colouration, and longer ears. In many ways it is reminiscent of Spencer's *P. eremiana* with which it was thought to agree until it was found that the proportions of the digits of the fore-feet agree with *P. bougainville* Q. & G., *P. myosura* Wagner, and *P.m. notina* Thomas, specimens of which are in the Museum's study collection.

When studying the material in the Australian Museum, E. le G. Troughton examined some Western Australian material, publishing his results in the Records of his Museum.[82] He reached the conclusion that *Sminthopsis foggatti* of Ramsay was a good species. Further, among specimens labelled *Sm. crassicaudata* he found a female preserved in spirits which showed so many points of difference that it was made the type of a new species *Sminthopsis granulipes* Troughton, with the type locality King George's Sound. "Col. G. Masters, 1869."

When material in our Museum was checked several skins were found which agreed with the description of this new species and extended the range northwards to Kulin, Marvel Loch and Nungarin. Reference to this extension was made in my paper of the same year.[83]

Another piece of research by Troughton was the "Revision of the Rabbit-Bandicoots.[84] In this paper the distribution, past and present together with the variation in size and pelage were discussed and conclusions drawn. *Macrotis lagotis lagotis* Reid is the form distributed over the greater part of the animal's range in W.A. though a new sub-species is described from Rawlinna on the Trans-Australian Railway, under the name of *M. lagotis interjecta* Troughton.

In 1934, the Trustees of the Australian Museum published Memoir VI., "A Check-list of the Mammals of Australia," by Tom Iredale and E. le G. Troughton in which the Mammalian fauna of the Continent is classified according to present practice. A number of familiar names are superseded by others which have been shown to have priority. The range of the species and sub-species is indicated and ample references are provided.

The following additions should be made. *Dasycercus cristicauda* (Krefft) occurs in the Eremaea at the Warburton Ranges, the Canning Stock Route and further west. *Sminthopsis hirtipes* Thomas also is known from the Canning Stock Route and *Antechinomys* from the Pilbara and the vicinity of Lake Grace in the south. *Lagorchestes conspicillatus leichardti* Gould has a wide range in the Kimberleys and *Satanellus hallucatus* ssp? is the common Dasyure of the Pilbara.

Subsequent work has been mainly concerned with nomenclature and distribution. Also the overseas centre of interest seems to have passed from London to New York after the death of Oldfield Thomas, for the articles on marsupials in the latest edition of the Encyclopedia Britannica are by American mammalogists and a number of articles have been published in the "American Museum Novitates" and the "Bulletins of the American Museum of Natural History."

In his Wallace's Line and the Distribution of Indo-Australian Mammals[85], Dr. H. C. Raven adopts a conservative attitude ; he does not recognise the suggested subdivisions of *Dasyurus*, *Phascogale*, *Pseudochirus*, *Phascolomys*,

[82] *Rec. Aust. Mus.*, XVII., No. 6., p. 349, 1932.
[83] *Jour. Roy. Soc. W. Aust.*, XIX., 1932–3, p. 21.
[84] *Aust. Zool.*, VII., p. 219, September, 1932.
[85] *Bull. Am. Mus. Nat. Hist.*, Vol. 68, article 4, 1935, p. 179.

or the larger form of *Macropus* and for *Wallabia* he uses the older *Protemnodon* of Owen[86] basing his opinion upon the dental characters of the genus, to which he adds *eugenii* and its sub-species, removing them from *Thylogale*.[87] When dealing with the material collected by the Archbold Expedition to New Guinea, Dr. G. H. H. Tate critically examined the marsupials obtained.[88] He did not recognise some of the genera of Iredale and Troughton reducing them to subgeneric rank and replacing the *Wallabia* of Trouessart by the older *Protemnodon* of Owen, following H. C. Raven in this respect.

"The Furred Animals of Australia," by E. le G. Troughton appeared in 1941. It presents an up-to-date account of our living mammals giving a wealth of information concerning distribution, relationship and habits. Space does not permit each species to be described in detail, the author depending upon the 25 coloured plates which, unfortunately, are not all that might be desired. But taken together with Le Souef and Burrell, it helps to form a complete monograph of the present day mammalian fauna of Australia and is therefore invaluable to all workers. A few errors present in the first edition are corrected in the second which appeared in 1943.

A valuable contribution to our knowledge "Adaptive Branching of the Kangaroo Family in Relation to Habitat," by H. C. Raven and W. K. Gregory appeared in 1946[89] and a careful study of the Dasyuridae by G. H. H. Tate followed last year.[90]

And what of the future ?

The fauna of the South-West is fairly well known and is unlikely to produce many forms new to Science. The vast interior, our section of the Eremaea is not more promising but the Kimberley area, though closely linked to the Northern Territory, presents many opportunities for the evolution of new forms whilst the North Western quarter, where the Eremaean species are pressing on to the coast and the South Western and Kimberley species seem to be making their last stand, may, as a result of the struggle, produce species and perhaps also genera not yet scientifically described.

But the need for investigation is urgent, collecting expeditions should be organised without delay as even the hardy supporters of the Australian coat-of-arms are threatened by the clamours of the pastoralist and the wheat farmer.

As regards the future of the fauna as a whole, let me quote from Francis Harper's "Extinct and Vanishing Mammals of the Old World."

> "Conditions in Australia are peculiar and exceptional, owing to the fact that its unique native mammalian fauna is predominantly marsupial, and so lowly organised as to be quite unfitted for coping with certain exotic and aggressive species introduced by civilised man. The chief of these are the European Red Fox, the Domestic Cat, the European Rabbit, the House Rats and the House Mouse. Further competition results from encroachment of hosts of sheep and cattle upon the ancestral

[86] *Proc. Roy. Soc., Lond.*, 21, No. 141, 1873, p. 128.
[87] See also Raven, H. C., and Gregory, W. K., "Adaptive Branching of the Kangaroo Family in Relation to Habitat." *Am. Mus. Nov.*, No. 1309, March, 1946.
[88] *Bull. Am. Mus. Nat. Hist.*, Vol. 73, article 4, 1937, p. 331.
[89] *Am. Mus. Nov.*, No. 1309.
[90] "On the Anatomy and Classification of the Dasyuridae." *Bull. Am. Mus. Nat. Hist.*, Vol. 88, article 3, 1947, p. 99.

grazing grounds of the herbivorous marsupials. An apparently minor predatory role is played by the Dingo (*Canis dingo*), which was presumably introduced by aboriginal man . . . .

"The serious depletion of the native fauna by these agencies is supplemented by widespread bush fires, by conversion of a vast acreage of wild land into crop or grazing lands, by the huge fur trade, by epizootic disease, and by the large-scale use of poisoned bait, which takes toll of many animals besides the pests against which it is directed.

"Is there no hope ?

"I think something may be done to improve the position. True, some species have already disappeared whilst others are on the decline through natural causes. But if we act at once, if we undertake active propaganda and make the public fauna-conscious ; if we make the reserves already in existence real sanctuaries for wild life by fencing out the rabbit and the fox and by forbidding access to domestic flocks and herds and, if the Fisheries and Game Department is enlarged so that the inspectors and game wardens can adequately pefrorm their functions, then I feel sure that our very efficient and enthusiastic Chief Guardian of Game can be relied upon to do his utmost to preserve and foster our unique and remarkable fauna—a national heritage that we hold in trust for generations to come. It is not ours to deal with as we wish."

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